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CHATHAM STAGED MIXING BURNER PROJECT

FINAL REPORT

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THE NEW BRUNSWICK ELECTRIC POWER COMMISSION

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1.0 LOW NO_x BURNER PROJECT - UNIT DESCRIPTION

The New Brunswick Electric Power Commission, in cooperation with the Federal Department of Energy, Mines and Resources, has constructed a pilot scale boiler simulator test furnace at its Chatham, N.B. plant. This facility includes a novel pulverized fuel burner which incorporates the distributed fuel/air mixing concept to enhance the capture of sulfur oxides using sorbents, and reduces the formation of nitrogen oxides.

The following sections describe the principal physical features of the unit.

1.1 Propane System

Propane is used to pre-heat the furnace to its operating temperature prior to the introduction of pulverized fuel. For this purpose a 1000 US gallon propane tank was installed along with the appropriate fittings and piping. The propane leaving the tank via a 3/4" line passes through a pressure reducing regulator which lowers the line from tank pressure to approximately 10 psig as it enters the plant. At this point an isolating valve is located in the line, followed by a pair of solenoid control valves, after which the propane flows through a flowmeter. Upon exiting the meter the propane flow passes through a throttling valve complete with delivery pressure gauge prior to entering the burner via a ½" section of copper tubing. Flow rate settings are manually effected by adjusting the throttling valve and observing the rate meter.

The solenoid valves are linked with a Honeywell automatic control system which utilizes an ultraviolet flame detector mounted on the combustor, along with a purge timer and rectification amplifier.

1.2 Solids Feeding System

The equipment used to feed both the fuel and sorbent to the combustor are virtually identical. A bin vent containing nine cloth filter bags sits atop a 100 cubic foot capacity main hopper. The bin vent is supplied with high pressure air to permit manually initiated pulse cleaning of the filter bags. The intake of the bin vent is normally sealed during operation, but is used to accommodate a four inch PVC vacuum hose when the bunker is to be filled. Motive force for loading the bunker is provided by the exhaust fan which is connected by four inch carbon steel piping and an isolation valve network to the bin vent discharge, situated on the clean side of the filters.

The main hopper has a cylindrical upper portion while the lower segment is conical. The lower extremity of the hopper leads into a bin vibrator. Immediately below the vibrator, an

8 inch pneumatically actuated butterfly valve is located. Material leaving the main hopper will pass vertically down through the vibrator and valve, into a 1.5 cubic foot screw feeder hopper via an interconnecting isolation bellows. This bellows, composed of flexible plastic material, segregates the screw feeder and its material charge from the feed system equipment above.

The variable speed screw feeders are mounted atop platform scales. The discharge cylinder of the screw feeder passes horizontally through another flexible isolation bellows, before the material leaves the auger and falls through a discharge chamber, into a rotary air lock valve. These valves rotate with nine individual pockets at a speed of 10 RPM, thus providing minimal interference in the establishment of a feed rate by the variable speed screw feeders. A ½" vent line runs from the discharge chamber/rotary valves back to the main hopper.

Material leaving the rotary valve falls into an eductor nozzle installed in the primary and tertiary combustion air process lines. This device results in the fuel and sorbent becoming pneumatically entrained in the primary and tertiary air flows respectively. The fuel and primary air are then conveyed to the burner by a 1½ inch flexible line, while the sorbent and tertiary air are carried to a four-way splitter by a 2½ inch flexible hose, and subsequently enter the furnace in four-one inch carbon steel lines. A sketch of the feeder arrangement is given in Figure 1.

The output signal from the weigh scales are linked to a continuous display as well as the Micon #101 automatic controller. The feed rate is determined through the loss in weight of the scale load in relation to time elapsed. This figure is automatically calculated by Micon #101 and visually updated each second, based on a 20 second range. The speed controller for the screw feeder is also linked with the automatic controller and can be adjusted by it autonomously. Alternatively the option to manually select the auger speed can be exercised by using the dial speed selector on the auger speed controller.

1.3 Combustion Air

The combustion air fan is a positive displacement rotary blower complete with a 15 HP motor which can deliver 300 SCFM @ 7 psig and 160°F. The air flow produced from the unit is divided into three process streams: primary, secondary and tertiary combustion air flows, and a bypass flow. Each of the combustion air flows is regulated by a pneumatic globe control valve and differential pressure orifice unit linked with the automatic control system. A manual adjustment valve is installed in the 2 inch bypass line, which vents to atmosphere.

The process air lines are primarily constructed of schedule 40 carbon steel pipe, with the solids conveying lines also containing sections of flexible line. The primary and tertiary lines both pass through eductor nozzles at which point solids are introduced to these lines. Upon exit from these devices each line is composed of flexible hose, to eliminate flow restrictions, until just before the burner/furnace where carbon steel pipe is again used. The tertiary line is a 2½ inch diameter hose while the primary line is 1½ inches in diameter. The hard piping prior to the burner/furnace contains a pressure gauge and temperature thermocouple well. Similarly, there is a pressure gauge located between the control valve and orifice meter and a thermocouple preceding the control valve in all three combustion air flows.

The primary air line enters the burner at a single point, while the 2 inch diameter carbon steel secondary line splits to accommodate four separate burner entry points accorded it. The tertiary air line employs a four-way splitter to divide into 4 individual 1 inch diameter lines which enter the top of the furnace, outboard of the burner, evenly distributed on an 18 inch diameter.

In line electric air heaters are available but were not used due to temperature limitations imposed by the flexible hose material.

1.4 Burner

The burner, located atop the furnace, accepts the primary air/fuel mixture through a single 1½ inch inlet near the top of its central shaft. This flow is then directed down through the central shaft and into the furnace. Secondary air enters the burner via four 2 inch ports located radially about the cylindrical swirl generator portion of the burner. Within the swirl generator are adjustable air foils which impart a turbulence to the secondary air as it enters the furnace through an annular region about the primary air/fuel injection tube.

In addition, the propane preheat fuel enters the burner at a point above the primary inlet on the central burner shaft, and is introduced to the combustor through a 3/8 inch tube of stainless steel which passes through the center of the primary feed pipe. Figure 2 presents a schematic of the burner design.

Propane ignition is accomplished through the use of an integral spark electrode which extends from the top to the lower tip of the burner.

The unit is constructed of carbon steel, excepting the propane handling portions which are brass. It has a nominal capacity of one million BTU/hr.

1.5 Furnace

The furnace is of modular construction consisting of 11 cylindrical units each 2 feet high, which produce an overall height of approximately 22 feet. The upper nine cylinders are essentially identical with a 40 inch OD carbon steel shell lined with eight inches of refractory to produce a two foot diameter gas path. In addition, two 8 x 8 inch water panels may be installed in each of these modules to provide cooling of the furnace gases. The units are assembled using upper and lower flanges and the entire furnace supported at a mid-elevation reinforced flange position. The refractory lined cover accommodates the burner and has 4 tertiary air ports built into it. As well, the cover contains an observation port and the ultraviolet flame detector. The observation port receives metered high pressure aspirating air on the hot side to provide cooling and limit fouling.

The tenth module has a horizontal combustion gas exit duct protruding from it, leading to the cyclone. The lowest module is a funnel shaped, water cooled conical section which shunts the bottom ash to the ash removal line. A pictorial representation of the unit is given in Figure 3. An 8" pipe U-tube has also been attached to module #10 to serve as a furnace high pressure relief device. Ten to twelve inches of water is placed in the bend of the pipe to absorb minor furnace "pulp". This line is vented to the atmosphere.

The furnace contains 3 sample probe access ports located at approximately 4'8", 7'8" and 14' below the burner plane. Other instrumentation includes pressure taps from both the upper and lower portion of the combustor and thermowells/thermocouples in the discharge flow from each water panel. The assembled furnace makes use of eight water panels in the first four modules, with one in each of the remaining five modules arranged in staggered pattern, for a total of 13 panels in service. A thermocouple is also located directly in the gas stream passing through the horizontal duct from the furnace to the cyclone, and there is one thermocouple embedded in the refractory wall of each of the upper nine modules. The embedded thermocouple is positioned one inch into the wall from the gas path.

1.6 Exhaust Train

The flue gas and entrained fly ash exit the lower portion of the furnace horizontally and pass into the cyclone. The cyclone is approximately 6½ feet high with a 2½ foot outside diameter. The refractory lining of this equipment produces a 1½ foot interior diameter and permits operation with gases of up to 2100°F. The outer shell of the cyclone is constructed of carbon steel.

Upon leaving the cyclone, the cleaned flue gases enter a two pass water cooled heat exchanger which reduces their temperature to a point where unlined carbon steel piping can be used. An eight inch pipe then directs the exhaust gases into a 3 HP exhaust fan which forces these gases through the stack, where they are emitted to the atmosphere. Thermocouples are located in the gas path at both the heat exchanger and exhaust fan discharges.

1.7 Ash Removal

Two identical 4½ foot high by 7 foot square hoppers with conical lower sections 2½ feet high are used to hold bottom ash from the furnace and fly ash from the cyclone. The 6 inch lining of these hoppers results in approximately 200 cubic feet of interior capacity each. The outer shell is constructed of carbon steel. The sealed design eliminates the need for a high temperature valve between the furnace/cyclone and the hoppers. An eight inch ID refractory lined pipe directs the bottom ash into one bunker while, the fly ash passes through a six inch ID refractory lined pipe from the cyclone to the other hopper.

1.8 Cooling Water

Municipal water is used to supply the cooling panels in the furnace, the water jacket in furnace Module #11, the fire tube heat exchanger and the water cooled gas probe. Vertical two inch water supply pipe stands run along opposite sides of the furnace, accompanied by three inch water drain pipe stands. Horizontal 3/4" pipe supply and drain connections run from these pipe stands to each of the 13 furnace water cooling panels. Manual valves on the inlet and outlet of each panel are used to throttle the water flow to the desired rate. The inlet lines to these panels also contain in-line flow totalizers and a pressure relief valve set at 95 psig, while the drain lines have a thermowell/thermocouple. These pipe stands also supply/drain Module #11.

A separate two inch water line containing an automatic globe control valve, thermocouple and flow totalizer, supplies the fire tube heat exchanger. The discharge line from the heat exchanger contains a pressure relief valve and a butterfly valve to back pressure the flow.

Both water panels and the heat exchanger have pressure relief valves installed.

1.9 Sampling and Analysis

The principal sampling device is the gas analysis system. The system is composed of a gas extraction probe, conveying

line, conditioning system and gas analyzers. The long cylindrical gas extraction probe is constructed of stainless steel and has an outside diameter of 2½ inches. This probe, shown in Figure 4, has an inner and outer water jacket and a usable length of 22 inches from tip to flange. Cooling water is supplied from a domestic electric hot water heater set at 180°F. The extracted sample passes from the probe through a number of insulated fittings before entering the conveying line. The conveying line is a ¼ inch heat traced teflon hose which carries the gas sample to the conditioning system at a temperature of 300°F.

The first phase of the conditioning system involves passing the sample through a filter positioned in a box which has a temperature maintained at about 110°C. After this the gas passes through a teflon coil in a refrigerant bath of 0°C which condenses the moisture in the sample. The moisture is trapped in a subsequent series of four glass impingers also situated in a refrigerated bath of approximately 2°C.

At this point the dried sample passes through several filters before entering an oven section, maintained at 85°C, where it is pulled through the sampling pump. The sample, now at approximately 10 psig, is then distributed to each of 5 gas analyzers. The analyzers available are as follows:

CO Analysis	Beckman Model 864 Non-Dispersive Infrared Analyzer
CO_2 Analysis	Beckman Model 864 Non-Dispersive Infrared Analyzer
SO_2 Analysis	Beckman Model 865 Non-Dispersive Infrared Analyzer
NO_x Analysis	Beckman Model 851A No_x/NO Chemiluminescent Analyzer
O_2 Analysis	Beckman Model 755 Paramagnetic Oxygen Analyzer

As well, type-K thermocouple probes were constructed for use in the furnace gas path to approximate gas temperatures. These probes are basically 3 foot long, inconel sheathed type-K thermocouples with collar type flange plates which permit access through the existing gas sampling ports.

Bottom and fly ash solid samples were collected from the ash hoppers and an initial ultimate, proximate and calorific analysis was done on the coals with a compositional analysis completed on the limestone.

1.10 Control

System control is primarily achieved through two Micon multi-loop controllers (#101 and #201). The Micon is a microprocessor based automatic controller capable of handling up to eight individual or interdependent control loops. The unit can perform a large array of alarm and logic sequence functions. It samples each loop 10 times per second and updates them 3 times per second. For this project, the equipment has been utilized as follows:

Micon #101	Control Drive	Control Variable	Control Parameter
Loop #1	Secondary Air Flow Valve	Orifice Press Drop	Secondary Air Flow
Loop #2	Tertiary Air Flow Valve	Orifice Press Drop	Tertiary Air Flow
Loop #3	Primary Air Flow Valve	Orifice Press Drop	Primary Air Flow
Loop #4	Tertiary Alternate Air Flow Valve	Orifice Press Drop	Tertiary Air Flow
Loop #5	Heat Exchanger Water Flow Valve	Gas Temperature	Gas Temperature
Loop #6	Coal Screw Feeder	Coal Scale Output	Coal Feed Rate
Loop #7	Sorbent Screw Feeder	Sorbent Scale Output	Sorbent Feed Rate
Micon #201			
Loop #1	Primary Electric Heater	Primary Temperature	Primary Air Temperature
Loop #2	Secondary Electric Heater	Secondary Air Temperature	Secondary Air Temperature
Loop #3	Tertiary Electric Heater	Tertiary Air Temperature	Tertiary Air Temperature

Micon #101, Loop #1 to #4 manipulate the flow control valves to maintain a specific pressure drop across the metering orifice. Since the pressure and temperature at this point is monitored it is possible to select the appropriate pressure drop corresponding to the desired air flow in each of these lines.

Loop #5 utilizes a thermocouple in the flue gas stream exiting the fire tube heat exchanger to adjust the water supply control valve to this piece of equipment in an effort to maintain a specific flue gas exit temperature.

Loops #6 and #7 involve the monitoring of coal and sorbent weigh scale outputs respectively over time. These loops determine an actual feed rate based on the loss in weight with time from the screw feeders mounted on the scales, and adjust the variable speed drives of the augers accordingly to attain a specific set point value. There is also an option to run the screw feeders manually.

Micon #201, Loops #1 to #3 receive signals from the temperature thermocouples located in the process air flow lines and turn on/off in-line electric air heaters as necessary to approach a particular set point value.

The propane safety controls are utilized when propane is introduced and burned in the unit. The purge switch will initiate a five minute purge cycle. Interlocks have been installed to ensure the combustion air fan and exhaust fan are both operating during the purge period. When the purge complete indication has been obtained the ignition switch may be depressed. This will open the propane solenoid valves, permitting propane flow into the furnace, as well as activating the spark ingnition system. If a successful flame ignition is not obtained within 15 seconds the solenoids will close and the purge cycle must be repeated before another attempt can be made at establishing a propane flame. However, should the gas ignite, the ultraviolet flame sensor will recognize this fact and maintain the propane flow, sustaining the flame. Loss of flame will again result in the solenoid valves closing, and the necessity of a purge before re-ignition can be attempted.

In addition to the propane control interlock, the fans are interlocked to one another such that the combustion air fan will not run unless the exhaust fan is running. The fans in turn are interlocked with the rotary valves of the feed system in such a way that these valves will not operate without the fans also operating. Finally, operation of the screw feeders are linked with the rotary valves being operated. The combustion air fan, exhaust fan and rotary valves have direct on/off controls which must be operated, however, with consideration of the existing interlock hierarchy.

The coal flame is observed visually by the operator through a closed circuit TV system which monitors the observation port atop the combustor.

The scale display electronics are used to automatically control the bin vibrators and refill butterfly valves located between the main hoppers and the auger feeder hoppers. At the preselected low weight the bin vibrator is started and the refill valve opened until enough material enters the lower hopper for the upper weight limit to be reached. At this time the valve closes and the bin vibrator is shut-off.

1.11 Data Acquisition

The principal data acquisition device is a multi-channel chart recorder which is used to record the following:

- temperature outputs from the nine type-R thermocouples imbedded in the refractory wall of the combustor.

- the flue gas temperature from the type-K thermocouple installed in the horizontal duct of the unit.

- the temperature of the cold water supply.

- the temperature of the gas exiting the exhaust fan.

- the primary, secondary and tertiary air temperatures at the burner level.

- the temperature provided by the furnace gas probe.

- the temperature of water exiting from the heat exchanger.

- the output of the coal and sorbent weighscales.

- the output of the five gas analyzers (including the 3 infrared signals which are linearized in the multi-loop controllers.

In addition a multi-channel thermocouple display is used to manually record the temperature of the water flow leaving each furnace cooling panel via the type-K thermocouples installed in the drain piping of each. This display also makes available the temperature of water entering the fire tube heat exchanger, the temperature of cooling water leaving the conical lower portion of the furnace and the sample gas temperature exiting the gas extraction probe.

Other data readily recorded manually from the automatic controller displays include:

- the primary, secondary and tertiary air flows (orifice pressure drops).

- the flue gas temperature exiting the fire tube heat exchanger.

- the coal and sorbent feed rates.

- the primary, secondary and tertiary air temperatures at the lower elevation.

Finally, additional data obtained manually from decentralized instrumentation include:

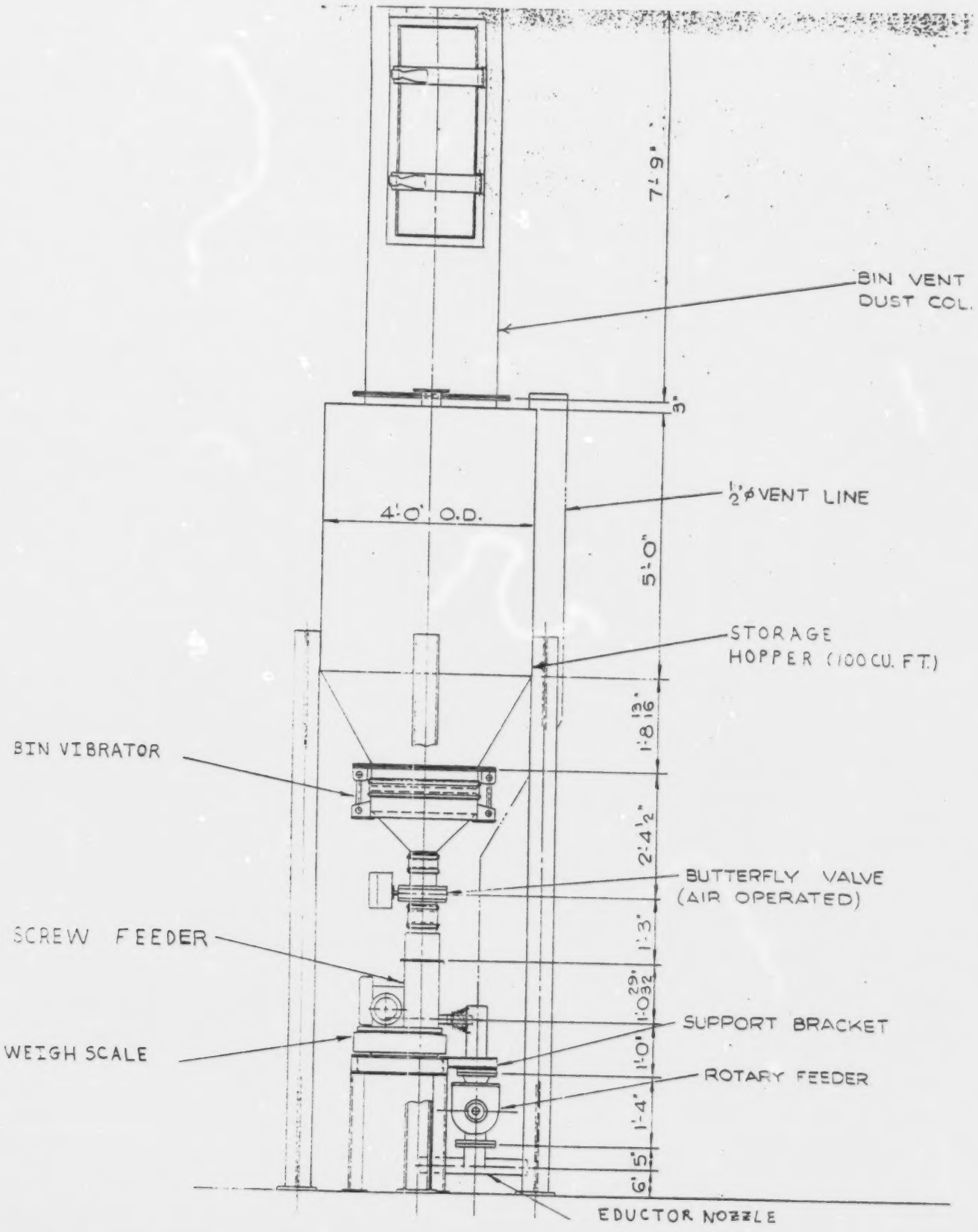
- primary, secondary and tertiary air process line pressures at the metering orifices.

- primary, secondary and tertiary air process line pressures at the burner/furnace.

- water flow rates to the heat exchanger and panels.

- gas analyzer outputs are recorded directly from the analog displays of the individual instruments.

FIGURE 1
LOW NO_x BURNER PROJECT
SOLIDS FEEDING SYSTEM



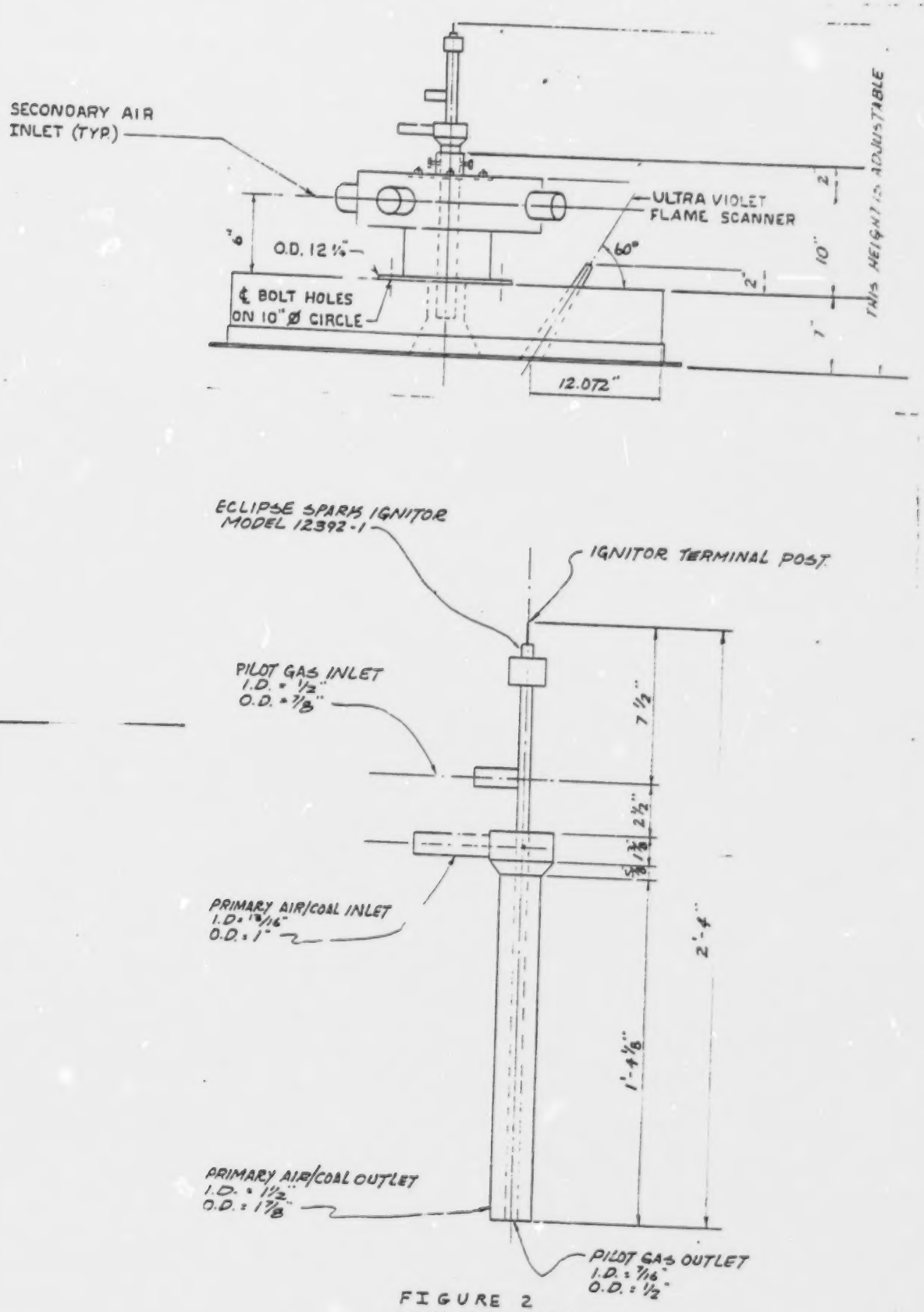
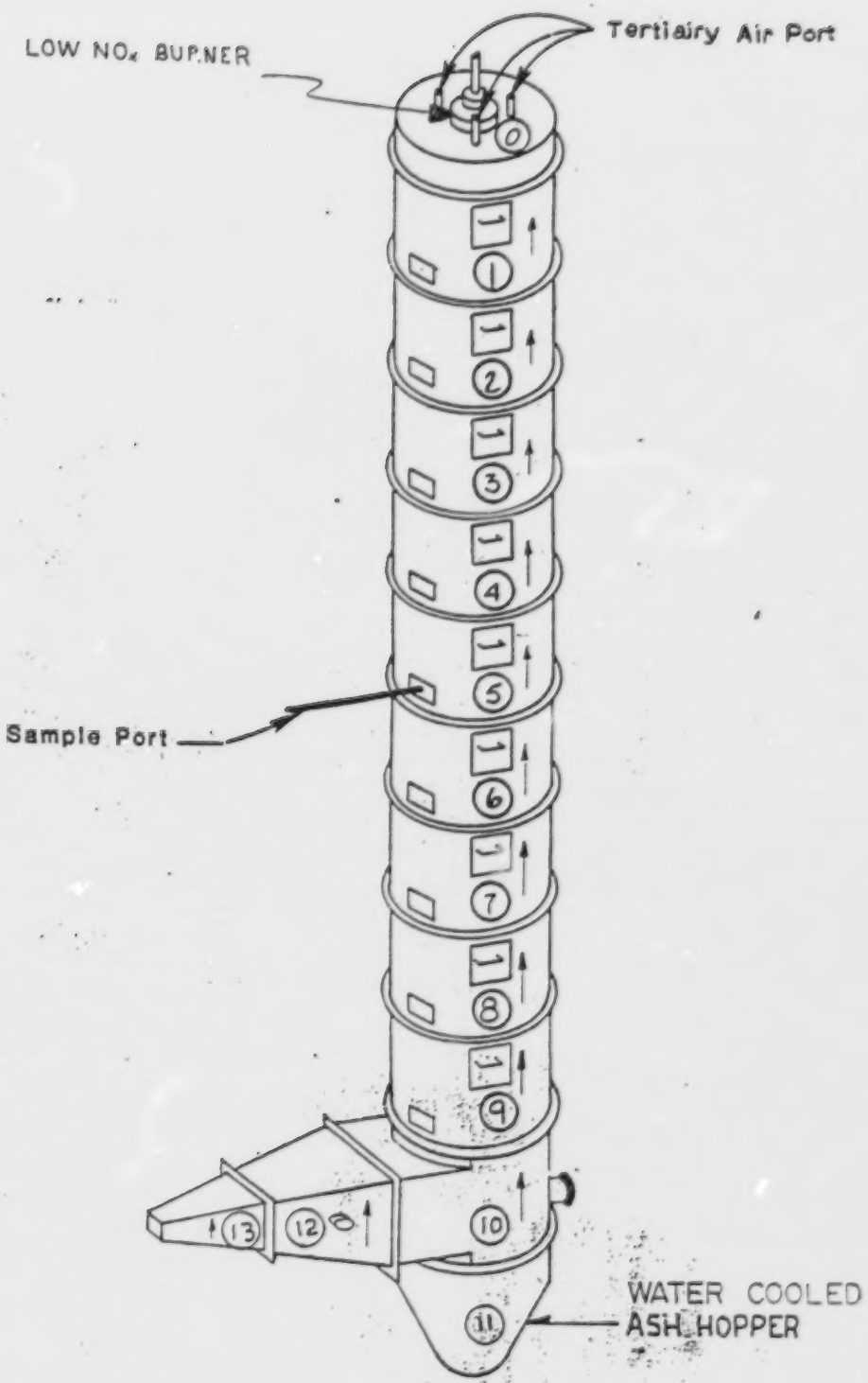


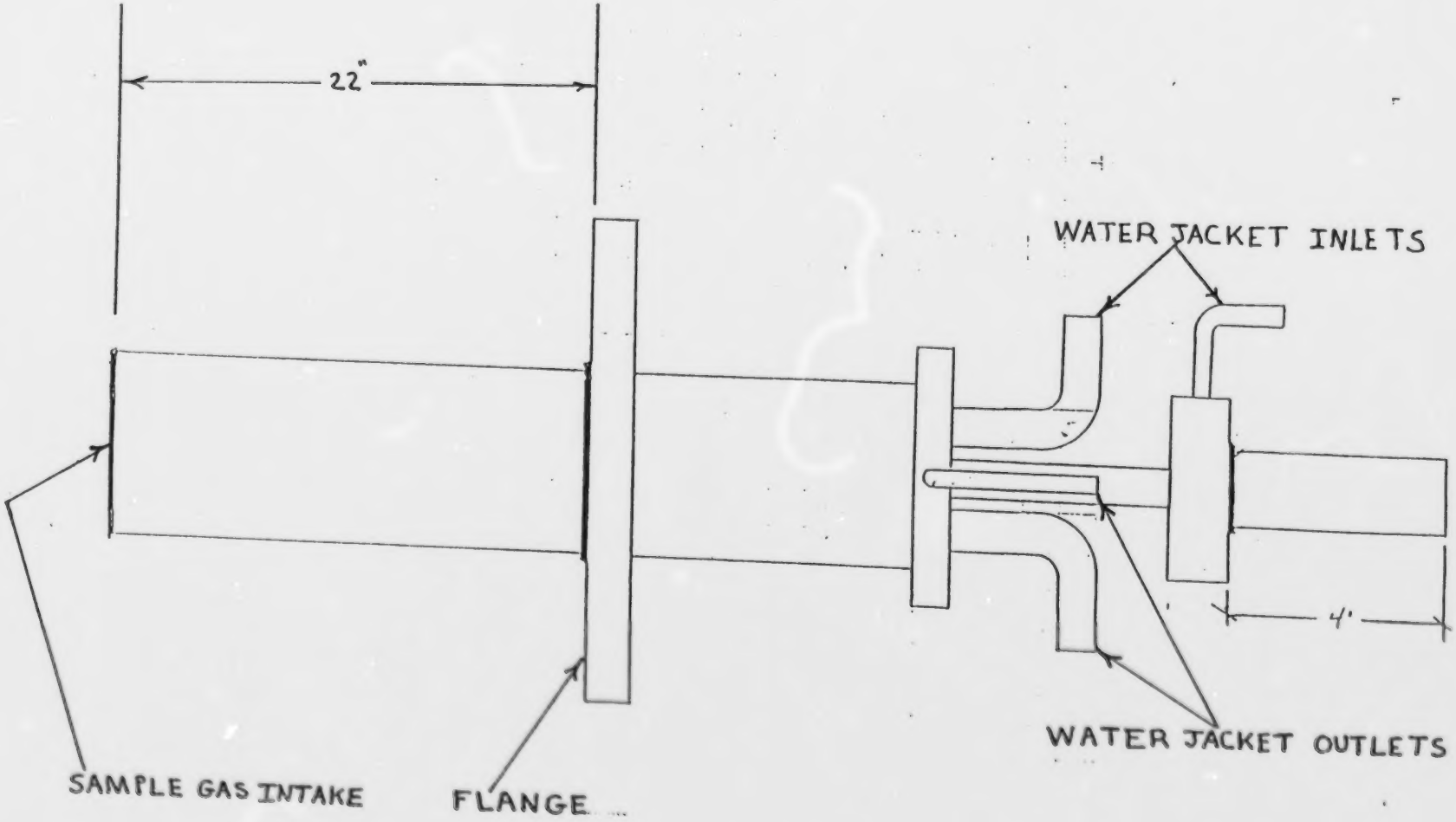
FIGURE 2
LOW NOx BURNER



FURNACE SCHEMATIC

FIGURE 3

T-1172-D



GAS SAMPLING PROBE
FIGURE 4

2.0 OPERATIONS

2.1 Start-Up

Prior to the commencement of a test sequence the furnace is purged and preheated to operating temperature using a propane flame. Temperature of the Module #3 thermocouple which is embedded in the refractory wall is monitored as a reference temperature. To prevent thermal damage to the refractory lining, the preheat rate at this point is limited to approximately 100°C per hour. Hence the unit requires approximately 6 to 8 hours to reach operating temperature. During this phase, cooling water flow is maintained in the furnace cooling panels and the heat exchanger.

When the reference temperature has been achieved, a coal flow is initiated, and the air flows adjusted according to the requirements of the particular test sequence being conducted. With the introduction of coal, the propane flame is removed and the coal rate fine tuned by manually adjusting the auger feeder controller dial. At this time a limestone feed rate, if desired, can also be established. Despite the availability of automatic control for the feed augers, quite satisfactory performance has been obtained by manually selecting the screw feeder speed and having it remain constant throughout the duration of a test. To date no automatic feed control burns have been run.

2.2 Test Procedure

2.2.1 Gas Measurements

The bulk of the test activities are encompassed in the gas analysis portion of the program. The extractive gas analysis probe is inserted to one of the three specified depths, (1.6 inches, 6 inches or 10 inches from the inside wall). Along the radius, at one of three particular elevations (4'8", 7'8" or 14') where sample probe access ports are located. The sample point locations are graphically illustrated in Figure 5. The probe is positioned and the unit sealed using a flange and spacer arrangement. The furnace is then pressurized to +1-2 inches W.G. by manual manipulation of valve 38100-V015 located at the exhaust fan inlet, eliminating the possibility of ambient air infiltration into the sample.

The sample is then extracted from the combustor with the water cooled insertion probe and conveyed to the conditioning system via a 30 foot heat traced teflon hose. The sample is then directed to the gas analysis instruments for corresponding compositional analysis of CO, CO_2, SO_2, NO_x and O_2. The gas analyzers are calibrated daily during testing operations.

The individual outputs are recorded manually from the analog displays of each instrument. The three infrared analyzer concentrations must be corrected for non-linearity using a calibration chart.

The gas temperature at each of the sampling points is obtained by the use of stainless steel sheathed thermocouples with flange collars installed. The measured temperature is recorded from channel 29 of the chart recorder.

2.2.2 Recorded Data

(a) Furnace Wall Temperatures

Furnace wall thermocouples embedded in the refractory of Modules Nos. 1 to 9 are continuously recorded and available on channels 12 to 20. These display valves are also recorded manually each hour.

(b) Sorbent and Coal Fuel Mass Feed Rates

The coal and sorbent feed rates are automatically calculated by the automatic controller #101, Loops #6 & #7, and the displayed rates updated each second, based on a 20 second recall. The rates are also checked by the operator using a stopwatch and the scale display valves. The final method for determining the feed rate is to utilize the chart recorder output where weight is plotted against time on channels 21 and 22 for coal and sorbent respectively.

(c) Combustion Gas Exit Temperature

The combustion gas exiting the furnace passes a type-K thermocouple situated in the horizontal duct leading to the cyclone. The output from this sensor is recorded continuously on channel 23, and recorded manually each hour.

(d) Cooling Water Temperature

The main cooling water supply temperature is recorded hourly by the operator as well as being continuously recorded on channel 24. It is available from thermocouple 67210-TC010.

(e) Primary, Secondary and Tertiary Air Temperatures

The temperatures of the primary, secondary and tertiary process air flows are measured by thermocouples 63110-TI002, TI001 and TI003 at a point near the orifice meters and continuously recorded on channels 25, 27 and 28 respectively.

(f) Heat Exchanger Discharge Water Temperature

The water leaving the heat exchanger is continuously monitored by thermocouple 67210-TC007, using channel 30 of the chart recorder and recorded hourly by the operator.

(g) Primary, Secondary and Teritary Air Flows

Automatic controller No. 101 has the pressure drop through the primary, secondary and tertiary metering orifices (63120-F0003,F0001,F0002) available on loops No.3, No.1 and No.2/4 respectively. This information is recorded hourly and is used to calculate the air flow rate in SCFM.

(h) Heat Exchanger Flue Gas Exit Temperature

Thermocouple 67210-TC005 located at the gas discharge of the heat exchanger provides a temperature which is recorded hourly from loop No.5 of controller No. 101.

(i) Process Air Pressures

Pressure gauges installed between the flow control valve and the metering orifice plate of the primary, secondary and tertiary air lines are read and recorded during each test. This information is used in computing the air flow rates.

Pressures delivered to the burner/furnace are obtained from appropriately located gauges during each test for all three combustion flows.

(j) Cooling Panel Discharge Water Temperature

Water exiting each of the 13 furnace cooling panels have a thermowell monitoring the exit temperature. This data is available on a multi-channel display unit and is manually recorded on an hourly basis.

2.3 Test Program

The test program was finalized after a series of initial preliminary burns which assessed the capabilities of the unit. It was designed to investigate the effect on NO_x and SO_x emissions of as many operational variables as were considered feasible. To this end, the following is a listing of the fixed parameters, followed by another, of those that were examined:

Fixed Variables

Secondary Air Swirl - burner setting was maintained at approximately 30% open.

Combustion Air Temperatures	-	due to the flexible hoses in the conveying lines, the electric pre-heaters were not utilized and the combustion air averaged 140°F.
Furnace Cooling	-	the furnace heat sink was maintained throughout all tests by using the same water flow through the cooling panels.
Primary Air Flow	-	the primary air which conveyed the fuel was maintained at 40 SCFM for the duration of the test program.
Excess Air	-	maintained nominally at 20%.

Test Parameters

Firing Rate	-	a high firing rate of 1×10^6 BTU/hr. as well as a low rate of 0.6×10^6 BTU/hr. were used.
Combustion Air Distribution	-	a high staging air ratio of 60% primary zone: 60% tertiary air and a low staging air ratio of 90% primary zone: 30% tertiary air was examined for the high firing rate. The lower firing rate utilized 60%: 60% and 90%: 40% combustion air distribution ratios. All percentages are reported relative to theoretical air required.
Fuels	-	both Minto coal and Devco coal were tested.
Ca:S Molar Ratio	-	ratios of 0, 1:1 and 2:1 were examined.

Flow rates of solids and combustion air were calculated based on the ultimate, proximate and calorific analysis of the coals and the limestone analysis supplied by the subcontractor prior to the commencement of the main test program.

The following chart outlines the basic 17 tests performed on each coal. It should be noted that the tests in Phase I were typically completed in a continuous burn involving three individual tests. The only parameter to be altered during this sequence was the Ca:S ratio which went from 0 to 1:1 and finally 2:1.

Coal Test Program

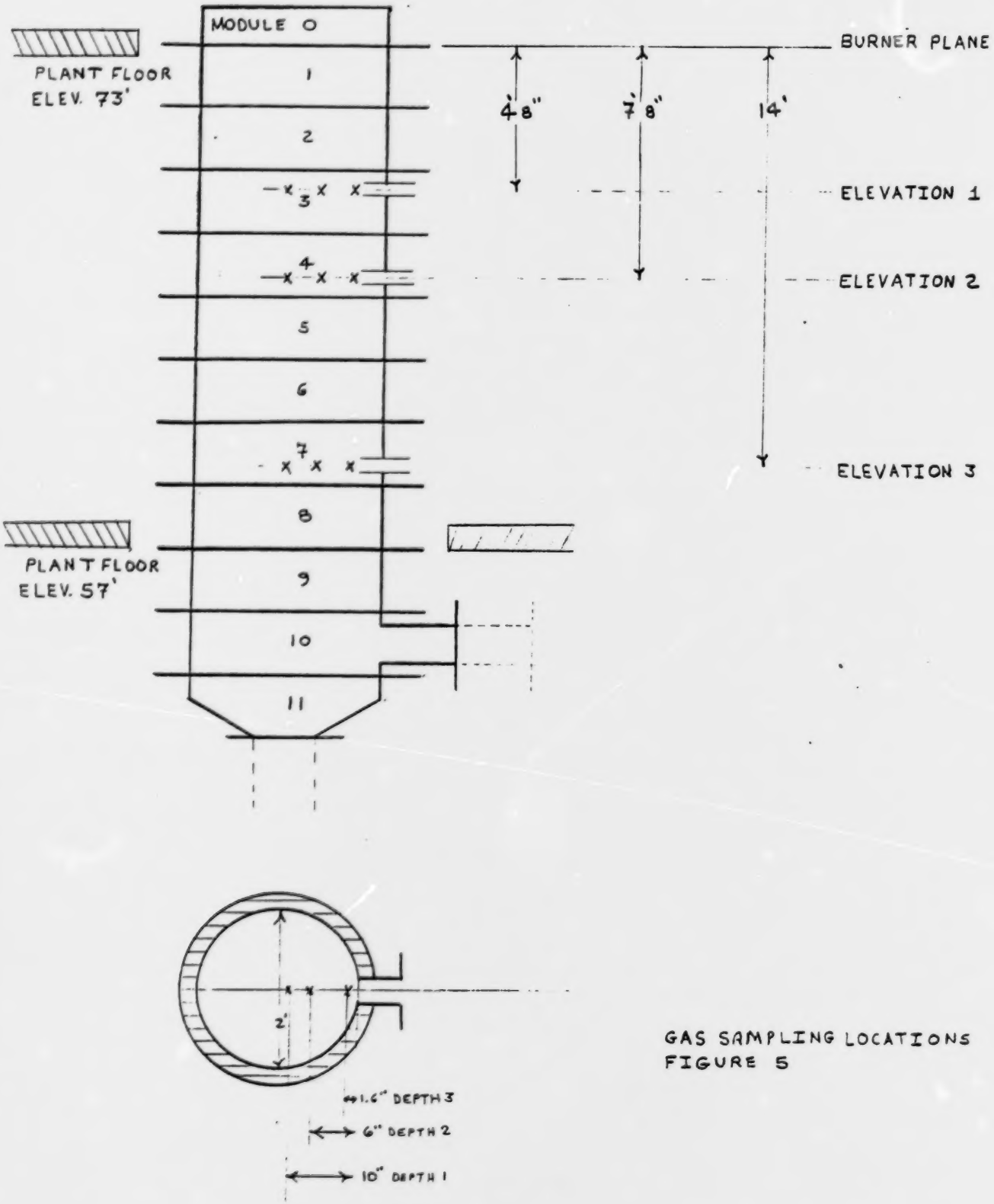
Phase I - Tertiary Injection

	Firing Rate	Comb. Air Ratio (%)	Ca:S Ratio (molar)
(a)	1×10^6 BTU/hr.	60:60	-
	"	"	1:1
	"	"	2:1
(b)	1×10^6 BTU/hr.	90:30	-
	"	"	1:1
	"	"	2:1
(c)	0.6×10^6 BTU/hr.	60:60	-
	"	"	1:1
	"	"	2:1
(d)	0.6×10^6 BTU/hr.	90:40	-
	"	"	1:1
	"	"	2:1
(e)	0.6×10^6 BTU/hr.	120:0	-

Phase II - Primary Injection

	Firing Rate	Comb. Air Ratio (%)	Ca:S Ratio (molar)
(a)	1×10^6 BTU/hr.	60:60	2:1
	"	90:30	2:1
(b)	0.6×10^6 BTU/hr.	60:60	2:1
	"	90:40	2:1

Again the combustion air percentage ratios given are relative to the quantity of theoretical air required. The distribution of this air indicated by the ratios is between the primary zone and the tertiary air flow. The primary zone is composed of both the primary and the secondary combustion air flows. The calcium to sulfur ratios have been obtained by injecting Havelock Limestone (38.2 wt.% calcium) through either tertiary or primary process lines into the combustor.



GAS SAMPLING LOCATIONS
FIGURE 5

3.0 TEST RESULTS

The following data was collected for each test: air and solid feed rates, gas analysis for CO, CO_2, O_2, SO_2, and NO_x, temperature records at nine positions in the furnace, and cooling panels inlet and outlet water temperatures. This data is given in Appendix II.

Tables 1 and 2 give the results in the form of excess air, combustion efficiency, sulphur reduction, NO_x emission and temperature profiles for Devco and Minto coal respectively. The sample calculations for Run # 24 may be found in Appendix III.

Sulphur reduction was lower than expected; some runs had negative sulphur reduction i.e. there was more sulphur leaving the system than was fed. The sulphur reduction number was corrected with respect to the baseline run (no limestone addition) for each set of conditions. It is assumed that the error in the mass balance was in the sulphur composition of the fuel, therefore for the baseline test, sulphur reduction is assumed to be zero and the sulphur composition of the fuel was calculated. This sulphur percentage in the fuel is then assumed for the tests under the same conditions with Ca/S ratios 1:1 and 2:1. Since these tests were performed on the same day, it is reasonable to assume that there was no change in the sulphur content of the fuel.

TABLE 1
PARAMETERS AND RESULTS FOR DEVCO COAL

Devco	Firing Rate (lbs/min)	Air Split	Ca/S	Excess Air (%)	Combustion Efficiency %	% S Reduction (measured)	% S Reduction (corrected)	NOx (lb/106 BTU)
23	1.65	50:50	0	19.6	93.9	-14.2	0	0.238
24	1.64	"	0.8:1	20.3	96.3	- 1.5	11.1	0.244
25	1.63	"	2.2:1	21.0	92.9	25.6	34.8	0.238
27	1.65	75:25	0	20.0	96.8	4.8	0	0.418
28	1.56	"	0.9:1	26.9	94.4	- 1.2	- 4.9	0.498
29	1.60	"	2.0:1	23.8	93.7	8.8	5.4	0.457
36	1.61	50:50	2:1 (B)	21.8	108.0	10.9		0.514
37	1.61	75:25	2:1 (B)	21.8	103.2	23.1		0.767
30	1.01	50:50	0	24.7	102.7	-20.8	0	0.263
31	1.00	"	2.0:1	26.0	104.5	-19.2	1.3	0.231
32	1.01	"	0.7:1	24.7	108.3	-23.8	- 1.2	0.212
33	1.00	69:31	0	35.9	106.8	-22.7	0	0.530
34	1.02	"	1.3:1	33.3	102.7	-10.6	10.8	0.512
35	1.00	"	2.3:1	35.9	106.9	- 9.2	12.1	0.443
38	1.00	50:50	2:1 (B)	24.1	115.0	51.8		0.589
39	0.86	69:31	2:1 (B)	44.3	113.2	36.6		1.030
26		100:0		4.7	83.5	25.1		0.509

NOTE: Air Split is Ratio of Percent of Total Air at Primary and Secondary Percent of Total Air at Tertiary

(B) Blended Injection

TABLE 2
PARAMETERS AND RESULTS FOR MINTO COAL

Minto	Firing Rate (lbs/min)	Air Split	Ca/S	Excess Air (%)	Combustion Efficiency %	% S Reduction (measured)	% S Reduction (corrected)	NOx (lb/106 BTU)
11	1.50	50:50	0	25.8	94.2	9.1	0	0.225
12	1.56	"	2.0:1	20.9	100.4	26.2	18.8	0.217
13	1.52	"	0.8:1	24.1	103.4	12.1	3.3	0.219
14	1.55	75:25	0	22.0	110.4	-10.2	0	0.346
15	1.52	"	1.0:1	24.4	110.7	- 7.2	2.8	0.365
16	1.54	"	2.0:1	22.0	109.4	2.8	11.8	0.285
40	1.50	50:50	2:1 (B)	22.6	111.1	14.0		0.335
41	1.50	75:25	2:1 (B)	22.6	124.8	13.8		0.453
17	1.02	50:50	0	26.2	102.4	11.8	0	0.337
18	1.06	"	0.9:1	21.4	102.3	3.0	-10.0	0.269
19	1.00	"	2.0:1	28.7	111.6	- 4.0	-18.0	0.290
20	1.15	69:31	0	20.6	113.3	-15.0	0	0.448
21	1.01	"	1.1:1	37.3	102.9	- 1.4	11.8	0.476
22	1.10	"	1.8:1	26.1	94.1	3.8	16.4	0.423
42	1.06	50:50	2:1 (B)	17.0	122.2	10.2		0.330
43	1.06	75:25	2:1 (B)	17.0	117.3	31.0		0.467

NOTE: Air Split is Ratio of Percent of Total Air at Primary and Secondary Percent of Total Air at Tertiary

(B) Blended Injection

4.0 DATA ANALYSIS

4.1 NO_x Emission

Pulverized coal combustion NO_x compound formation is produced from two distinct sources:

1) from the molecular nitrogen fraction in the combustion air (Thermal NO_x)

2) from the nitrogen which is chemically fixed in the fuel (Fuel NO_x)

Previous research has indicated that the formation of thermal NO_x is strongly temperature dependent. As well oxygen concentration and the residence time at peak temperatures also have a direct relationship to the quantity of thermal NO_x produced. However, the dominant mechanism for NO_x production in p.c. combustors is the oxidation of fuel nitrogen compounds to fuel NO_x. Again extended residence times at high temperatures greatly increases NO_x production, but two other important parameters in this process are fuel oxygen/nitrogen ratio and absolute fuel nitrogen content.

Test NO_x data is presented in Tables 1, 2, 3 and figure 6.

4.1.1 Effect of Limestone Injection on NO_x Emissions

As can be seen in Tables 1 and 2, the injection of limestone for a specific air distribution and firing rate does not seem to produce a significant effect on the NO_x emission rate. However, it is observed that the addition of limestone directly to the fuel results in generally greater levels of NO_x formation than the corresponding tests where limestone had been injected via the tertiary air. For Devco coal the increase is almost 50%, and approximately 30% for Minto fuel.

4.1.2 Effect of Air Distribution on NO_x Emissions

The two air distributions used for each firing rate represent a high (50:50) and a low (75:25) staging air situation where the first figure represents the percentage of total combustion air in the primary zone (primary and secondary air) while the second figure is the percentage in the tertiary air flow. The high staging air burns demonstrated on obvious reduction in the level of NO_x production relative to the low staging air tests, with the reductions ranging from 33% for Minto coal to approximately 50% with Devco coal. Blended test NO_x reduction averaged 28% and 38% for Minto and Devco fuels respectively.

The decreased NO_x levels during the 50:50 Air Distribution burns are attibuted to the lower oxygen concentrations in the high temperature zone where pyrolysis of the fuel occurs. The temperature differences due to variation of the staging air ratio do not appear to be significant at the elevations where measurements were taken, however it is thought that the peak flame temperature and therefore the NO_x production, is greater for the minimum staging air condition.

4.1.3 Effect of Firing Rate on NO_x Emissions

A general trend of greater NO_x emissions for lower firing rate is observed in the data, despite the lower flame temperatures generated during $0.6*10^6$ Btu/hr firing relative to the $1*10^6$ Btu/hr firing rate. It is suggested that the greater residence time in the high temperature region of the combustor above port 1 during the low firing rate may be the principal factor in producing this trend, although this situation is not consistent for all test sequences differing only in thermal input rate.

4.1.4 Effect of Fuel on NO_x Emissions

For corresponding test sequences it was found that the Devco coal produced a greater quantity of NO_x per 10^6 Btu input. This pattern is as expected when the analysis of the two fuels utilized are compared. Devco has a nitrogen content of 1.4 times that of the Minto fuel, as well the ratio of fuel oxygen to fuel nitrogen for Devco coal is 7.27 while that ratio for Minto coal is 5.09.

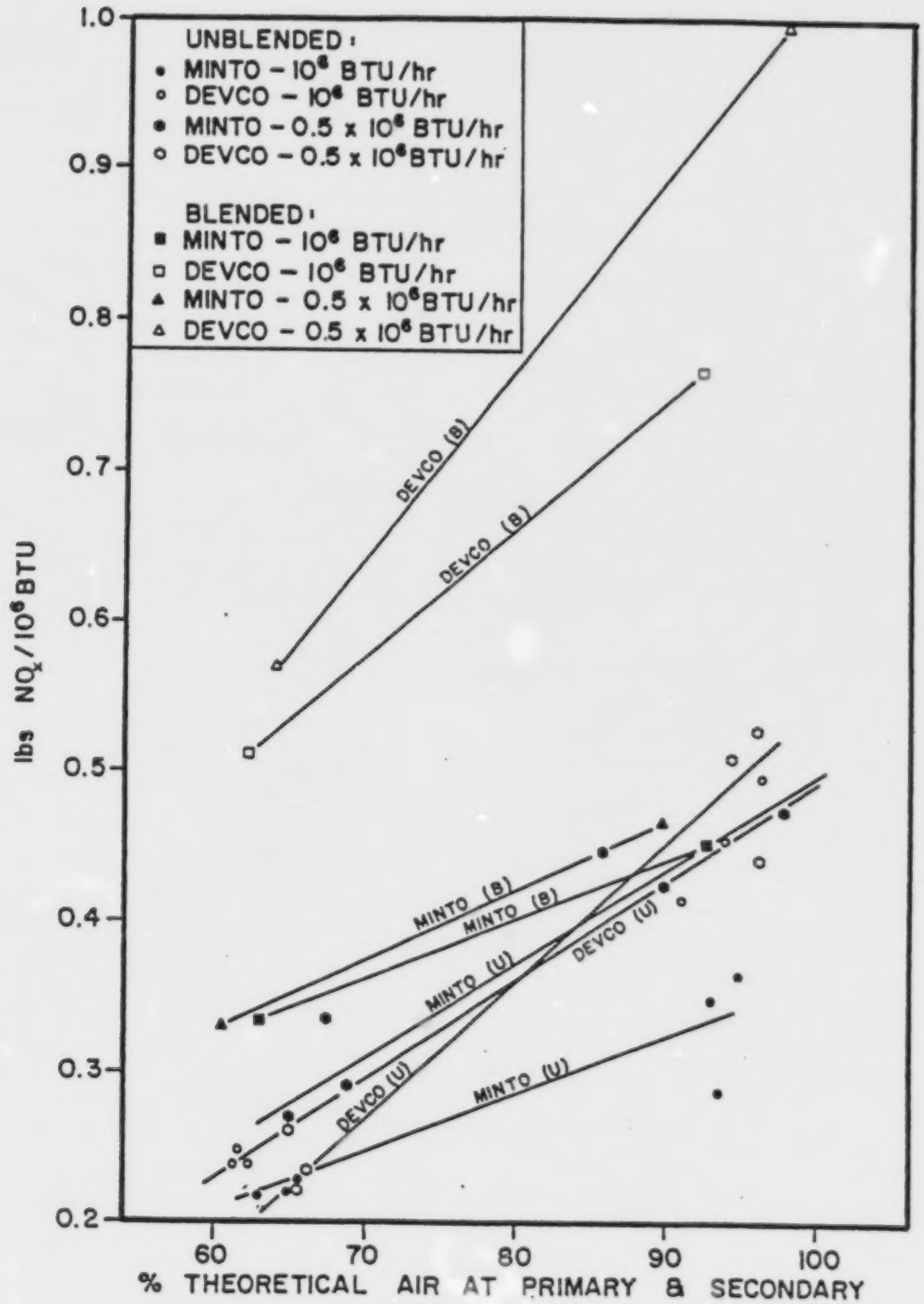


FIGURE 6: EFFECT OF AIR STAGING AND LIMESTONE INJECTION METHOD ON NO_x EMISSION

Temperature - Velocity - Time Profiles

Table 3

	Gas Temperature (°C)						Flue Gas
1. Minto Coal $1*10^6$ Btu/hr 50:50 Air Dist 0.220 lbNO_x/10^6 Btu	Depth	1	2	3	AVG	VEL.(ft/s)	Δt(s)	t(s)
	Port							
	1	1324	1327	1270	1307	6.41	0.73	0.73
	2	1220	1227	1155	1201	5.98	0.48	1.21
	3	1010	990	953	984	5.10	1.14	2.35
2. Minto Coal $1.0*10^6$ Btu/hr 75:25 Air Dist 0.332 lbNO_x/10^6 Btu	Depth	1	2	3	AVG	VEL.(ft/s)	Δt(s)	t(s)
	Port							
	1	1319	1319	1219	1285	6.32	0.74	0.74
	2	1217	1223	1156	1199	5.97	0.48	1.23
	3	1019	1025	966	1003	5.17	1.14	2.37
3. Minto Coal $0.6*10^6$ Btu/hr 50:50 Air Dist 0.299 lbNO_x/10^6 Btu	Depth	1	2	3	AVG	VEL.(ft/s)	Δt(s)	t(s)
	Port							
	1	1235	1227	1137	1200	4.36	1.07	1.07
	2	1107	1099	1039	1082	4.01	0.72	1.79
	3	841	835	792	823	3.24	1.75	3.54

Temperature - Velocity - Time Profiles

Table 3

4. Minto Coal
$0.6*10^6$ Btu/hr
70:30 Air Dist
0.482 lbNO_x/10^6 Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1228	1223	1136	1196	4.34	1.07	1.07
2	1116	1115	1054	1095	4.05	0.72	1.79
3	842	840	801	823	3.24	1.74	3.53

5. Devco Coal
$1.0*10^6$ Btu/hr
50:50 Air Dist
0.240 lbNO_x/10^6 Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1258	1268	1211	1246	6.07	0.77	0.77
2	1176	1160	1098	1145	5.67	0.51	1.28
3	939	917	838	898	4.68	1.22	2.50

6. Devco Coal
$1.0*10^6$ Btu/hr
75:25 Air Dist
0.456 lbNO_x/10^6 Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1347	1350	1295	1330	6.40	0.73	0.73
2	1245	1237	1186	1223	5.98	0.48	1.21
3	1019	1009	972	1000	5.08	1.14	2.35

Temperature - Velocity - Time Profiles

Table 3

7. Devco Coal
$0.6*10^6$ Btu/hr
50:50 Air Dist
0.235 lbNO_x/10^6 Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δt(s)	t(s)
Port							
1	1269	1271	1212	1215	4.10	1.14	1.14
2	1150	1145	1090	1128	3.86	0.75	1.89
3	924	924	878	909	3.25	1.78	3.67

8. Devco Coal
$0.6*10^6$ Btu/hr
70:30 Air Dist
0.495 lbNO_x/10^6 Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δt(s)	t(s)
Port							
1	1235	1231	1168	1211	4.09	1.14	1.14
2	1100	1098	1032	1077	3.72	0.77	1.91
3	872	864	845	860	3.12	1.85	3.76

9. Devco Coal Blended
$1*10^6$ Btu/hr
50:50 Air Dist
0.514 lbNO_x/10^6 Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δt(s)	t(s)
Port							
1	1337	1293	1211	1280	6.13	0.76	0.76
2	1208	1207	1141	1185	5.76	0.50	1.26
3	991	985	937	971	4.91	1.19	2.45

Temperature - Velocity - Time Profiles

Table 3

10. Devco Coal Blended
$1*10^6$ Btu/hr
75:25 Air Dist.
0.767 $lbNO_x/10^6$ Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1321	1323	1276	1307	6.24	0.75	0.75
2	1225	1216	1098	1180	5.74	0.50	1.25
3	986	971	939	965	4.88	1.19	2.44

11. Devco Coal Blended
$0.6*10^6$ Btu/hr
50:50 Air Dist.
0.589 $lbNO_x/10^6$ Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1145	1108	1054	1102	3.54	1.32	1.32
2	1016	983	881	960	3.17	0.89	2.21
3	761	746	670	726	2.56	2.20	4.41

12. Devco Coal Blended
$0.6*10^6$ Btu/hr
70:30 Air Dist.
1.030 $lbNO_x/10^6$ Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1105	1125	1035	1088	3.75	1.24	1.24
2	1024	951	866	997	3.36	0.84	2.08
3	808	802	689	766	2.86	2.03	4.11

Temperature - Velocity - Time Profiles

Table 3

13.Minto Coal
$1*10^6$ Btu/hr
50:50 Air Dist.
0.335 $lbNO_x/10^6$ Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1343	1341	1240	1308	6.24	0.75	0.75
2	1255	1248	1139	1214	5.87	0.50	1.25
3	1112	1105	1041	1086	5.36	1.13	2.38

14.Minto Coal
$1*10^6$ Btu/hr
75:25 Air Dist.
0.453 $lbNO_x/10^6$ Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1348	1349	1239	1312	6.26	0.74	0.74
2	1263	1257	1142	1221	5.90	0.49	1.23
3	1052	1037	990	1026	5.13	1.15	2.38

15.Minto Coal
$0.6*10^6$ Btu/hr
50:50 Air Dist.
0.330 $lbNO_x/10^6$ Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1297	1248	1177	1241	4.03	1.15	1.15
2	1166	1160	1030	1119	3.71	0.78	1.93
3	950	962	871	928	3.20	1.83	3.76

Temperature - Velocity - Time Profiles

Table 3

16.Minto Coal
0.6*10^{6}Btu/hr
70:30 Air Dist
0.467 lbNO_x/10^{6}Btu

Depth	1	2	3	AVG	VEL.(ft/s)	Δ t(s)	t(s)
Port							
1	1233	1215	1153	1200	3.92	1.18	1.18
2	1138	1131	1040	1103	3.66	0.79	1.97
3	919	912	884	905	3.14	1.86	3.83

4.2 SO_2 Emission

Sulfur dioxide, a natural product of coal combustion, forms as the sulfur in the fuel is reached in an oxidizing environment. This gaseous contaminant may be trapped in the process ash by reacting with calcined limestone to form $CaSO_4$. The optimum temperature for this reaction is 1000 to 1200°C.[4] At temperatures above 1300°C significant loss of surface area (sintering) will occur as the limestone calcines reducing its ability to fix SO_2 . Other parameters which strongly influence the degree of sulfur capture by limestone injection include the size distribution of the limestone, the calcium to sulfur ratio and the injection location.

4.2.1 Effect of Ca/S Ratio on Sulfur Reduction

The effect of calcium to sulfur ratio on sulfur reduction is shown in figure 7. As the calcium to sulfur ratio is increased the sulfur reduction is also seen to increase. The negative sulfur reductions may be due to errors in the determination of the sulfur content of the fuel, unsteady feed conditions and certain features of the gas analysis system.

4.3 Effect of Firing Rate, Staging, and Limestone Injection on Sulfur Reduction

4.3.1. Devco Coal

a) High firing rate vs. staging

At the high firing rate (1 million BTU/hr), high staging has a better effect on sulfur capture. Run numbers 23 to 25 show an overall better reduction than runs 27 to 29 (high firing, low staging); refer to Table 1. Since calcium reactivity is decreased at high temperatures, the higher air flow through the tertiary line, through which limestone is injected into the furnace, may be cooling the flame in such a way as to enhance calcium reactivity thus enabling better sulfur capture.

b) Low firing rate vs. staging

A comparison of tests at low firing rate with respect to air staging could not be reliable since run #32 is in error. It is believed that low firing rates would result in a better sulfur capture because of the increased residence time in the furnace, but the results are not conclusive.

c) Limestone injection location

The runs with the coal and limestone blended and injected with the primary air, generally give a better sulfur capture than those where the limestone is injected with the tertiary air. The best sulfur capture is obtained when the air staging is high and the coal firing rate is low (run #38).

4.3.2 Minto Coal

a) High firing rate vs. staging

For Minto coal, there does not seem to be any significant difference on sulfur reduction values when the air staging is varied. (Compare runs #11-13 with #14-16 in Table II). In comparing the same runs with Devco coal, the Devco runs had better sulfur capture, which is reasonable since Devco is a lower sulfur coal as compared to Minto.

b) Low firing rate vs. staging

A comparison could not be made in this respect since runs #17 to #19 are not reliable.

c) Limestone injection location

The results indicate that for Minto coal, low firing rate and low staging is conducive for better sulfur reduction with blended limestone injection (run #40-43).

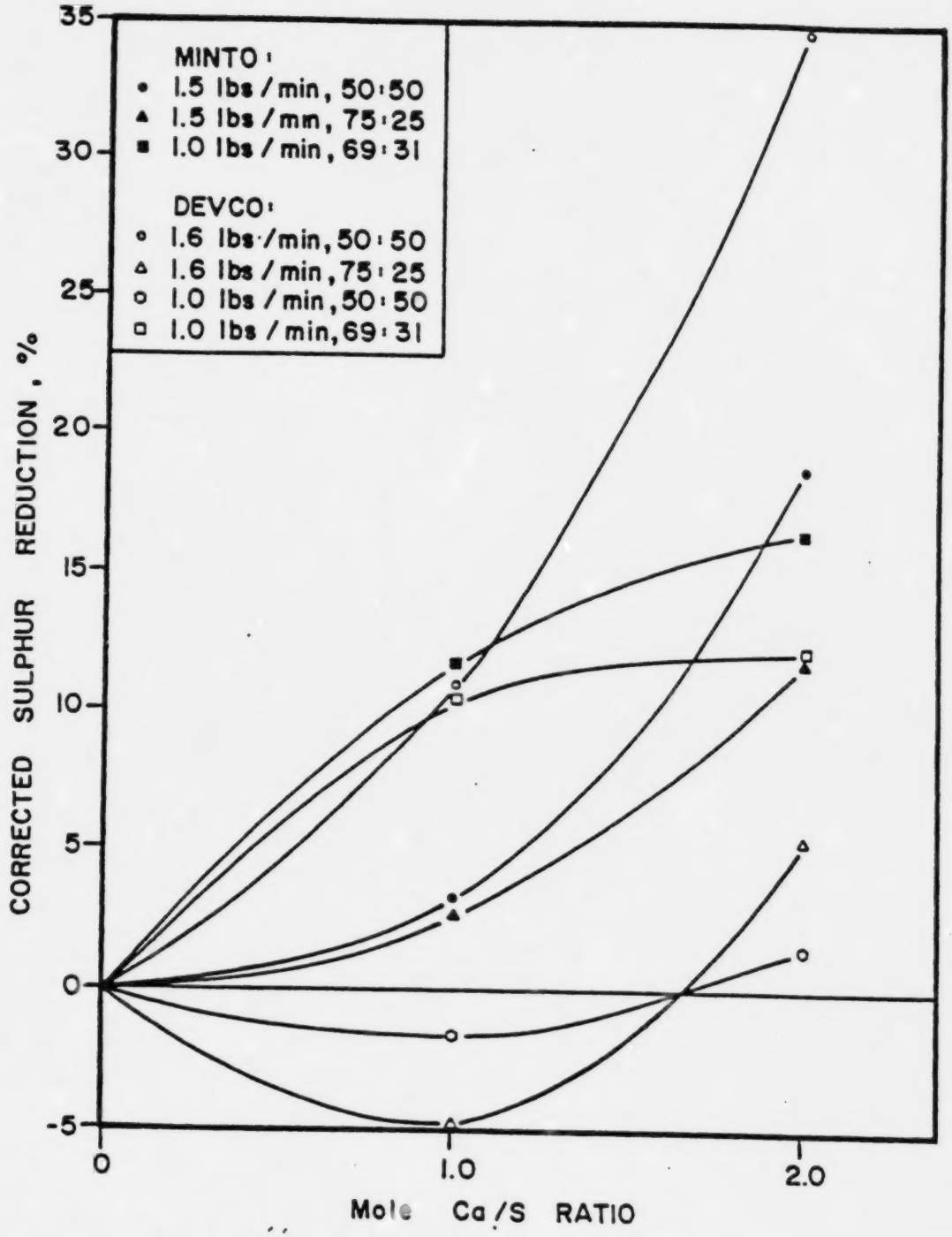


FIGURE 7 : EFFECT OF CALCIUM/SULPHUR RATIO ON SULPHUR REDUCTION

5.0 CONCLUSIONS AND RECOMMENDATIONS

1) The calcium to sulfur ratio during tertiary sorbent injection has a negligible effect on the NO_x generated.

2) Limestone blending with the fuel produces relatively greater amounts of NO_x when compared with tertiary sorbent injection.

3) A decided reduction in NO_x formation occurs when the high staging air operation mode is employed relative to the NO_x concentration observed during the low staging air distribution tests.

4) The lower firing rate generally produces a greater NO_x emission rate than that of the higher firing rate for a fixed set of parameters.

5) There is obviously a relationship between the oxygen and nitrogen content of the fuel and the quantity of NO_x it produces.

6) Generally sulfur capture improved with increasing Ca/S ratio.

The results of this initial phase of operations are primarily useful in indicating trends and characterizing the operating ranges of the unit. For definitive data to be generated it is recommended that a larger test program be conducted which would also allow for reproducibility trials to verify results.

A number of difficulties have been pinpointed as likely factors in the inconclusiveness of the SO_x fixation portion of the exercises. Firstly, the feed systems which deliver both the fuel and sorbent to the combustor were believed to be functioning inconsistently. This belief was reinforced by the cyclic compositional variation observed in the gas analysis instrumentation. Throughout the program refinements were made to improve the system, though none proved completely satisfactory. It is recommended that the reliability of the feed system be substantially improved prior to further testing. In a related manner, it is also recommended that higher calcium to sulfur ratios be investigated as the nature of the feed system is not well suited to metered delivery of relatively small quantities of sorbent. Further, published research indicates that higher Ca/S ratios than used in this study are optimum for this method of sulfur fixation.

Another factor influencing the measured sulfur content of the flue gas is the particular sample gas extraction probe design used. This system permitted an internal ash deposit to be built up through which the sample gas would be drawn prior to being analyzed. Depending on the composition of the deposit, the SO_2 content could be significantly altered. Further the

flue gas analysis system train contained a PVC portion initially, and the sample gas flow passes over moisture in the sample gas condensor reservoir. This arrangement may also have altered the SO_2 concentration monitored. It is recommended that the integrety of the gas analysis system, particularly as it relates to the determination of SO_2 concentration, be improved.

Finally, the experience gained from initial operations points to an increase in the quantity of fuel and sorbent analysis required. This practice is also recommended, particularly in view of the extensive lab facility now operating at this site.

A more complete definition of the combustor temperature profile is required. As well a suction pyrometer should be used for these measurements. It is recommended that a suitable instrument be obtained and all available sampling locations be used. This information will be essential if sorbent injection location is to be optimized to take full advantage of the available favorable sulfur capture temperature window in the unit.

The flowmeters on the water-panels are presently non-functioning. It is recommended they be repared/replaced as required so that an overall heat balance may be performed on the unit.

The construction of the ash collection system does not permit easy access or removal of all the residue from combustion trials. A grab sample should be obtained from the combustor using an appropriate combustor probe.

6.0 OIL SHALE OPERATIONS

Oil shale is a finely grained sedimentry rock containing organic matter in the form of kerogen (oils) as well as varying quantities of clay, dolomite, quartz and feldspar. The material is found throughout the southeastern region of New Brunswick. Chemical analysis of oil shale has found that significant concentrations (up to 15%) of calcium can be found in some of the deposits. As well, heating values ranging up to 3000 Btu/lb have been attributed to specific areas of the reserve. The co-combustion of oil shale with sulfur rich coal is an attempt to exploit both the calcium content of the oil shale for sulfur fixation and to utilize the inherent heating value of the material. This phase of the project is aimed at examining the technical feasibility of such a combined firing.

6.1 Procedure

Initially pulverized oil shale was fed through the sorbent feed system via the tertiary air flow into a cold combustor to access the ability of the delivery system to cope with this material and the feed rates if required. Successive intervals in which the oil shale was fed at 2.0, 2.5 and 3.0 lb/min were conducted without any difficulties arising.

Following this a co-combustion of oil shale and Minto coal was performed. The feed rates utilized were 2.7 lbs/min of oil shale and 1.0 lb/min of Minto coal. Though the oil shale feed auger was operating near its maximum and a great deal of motion could be observed in the screw feeder assembly mounted atop the scale, this did not noticeably affect the weigh scale output and hence the feed rate determination.

6.2 Data

6.2.1 Coal Base Line @ $1.0 * 10^6$ Btu/hr

Minto Coal	1.5 lb/min
Oil Shale	--
Primary Air	40 SCFM
Secondary Air	65.5 SCFM
Tertiary Air	105.5 SCFM
Excess Air	20%

Sample Location		3-1	3-2	3-3
ppm	CO	250-1400	750-2100	750-1400
%	CO_2	13.8	14.4	14.8
%	SO_2	0.54	0.55	0.57
%	O_2	4.5	3.5	3.5
ppm	NO_x	330	300	31[illegible]

6.2.2 Coal/Oil Shale @ 1.0 * 10^6 Btu/hr

Minto Coal	1.0 lb/min
Oil Shale	2.7 lb/min
Primary Air	40 SCFM
Secondary Air	76.7 SCFM
Tertiary Air	116.7 SCFM
Excess Air	20%
Ca:S	2:1

Sample Location		3-1	3-2	3-3
ppm	CO	250-750	250	150
%	CO_2	15.9	12.9	13.2
%	SO_2	0.56	0.45	0.51
%	O_2	4.5	5.3	5.5
ppm	NO_x	640	675	690

6.2.3 Oil Shale

Moisture	1.22%
Ash	81.22%
Sulfur	0.76%
Calcium	4.5%
LHV	1665 Btu/lb

6.3 Discussion

The feed rates selected were calculated after assuming that the oil shale contained 2100 Btu/lb and approximately 7% Ca. Lab analysis of the actual material used however, revealed that the thermal value was 1,635 Btu/lb and the calcium content 4.5%. This reduced the actual firing rate to $0.92 * 10^6$ Btu/hr and the Ca:S molar ratio to 1.28.

While only a marginal reduction in SO_2 emission was noted, the data shows a twofold increase in NO_x production when the oil shale and coal are fired together. This can be attributed to the fact that for the coal only case the primary zone contains only 60% theoretical air, while for co-combustion the primary zone contains approximately 83% theoretical air relative to the coal flow. As well, with the reduced thermal value of the oil shale, the effective excess air is actually greater.

The visible portion of the flame and the stack emissions were judged satisfactory. A subsequent Btu determination on the fly ash generated from this trial indicated no heating value was present in this material, implying the oil shale/coal had indeed burned with a high degree of efficiency.

6.4 Conclusions

It is apparent that pulverized oil shale can be successfully fed to the unit, up to a limiting rate, and efficiently co-combusted with coal.

There is potential for oil shale to be utilized as a sulfur fixation agent, but it appears this will be at the expense of greater NO_x emissions.

Oil shale of suitable quality must be used in further trials (appropriate calorific value, calcium content and size distribution).

APPENDIX I

CONTENTS:

- Gas Concentrations and Temperature Data for Runs # 11 to 32
- Cooling Panel Inlet and Outlet Water Temperatures
- Analysis of Coals and Limestone

Run: 11 Date: 3/6/86 Time: 10:45

Coal: Minto Ca/S: -

Feed Rates:

Primary Air:	40	SCFM
Secondary Air:	65.5	SCFM
Tertiary Air:	105.5	SCFM
Purge:	10	SCFM
Coal:	1.50	lbs/min
Limestone:	-	

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10.000+	15.2	1.5-2.0	0.56	290	1303
1-2	8,800-9,600	14.8	1.5	0.52	300	1311
1-3	5,300-9,600	15.2-15.4	1.0	0.56	320	1239
2-1	5,000-5,600	13.4	3.4-4.0	0.52	280	1212
2-2	4,800-8,700	15.8	1.0-1.5	0.60	260	1222
2-3	4,400-6,600	15.8-16.2	1.0	0.66-0.68	270-280	1205
3-1	400-4,200	14.1-14.8	4.0-5.0	0.49-0.50	240-260	912
3-2	500-1,400	11.4-12.9	5.0-5.5	0.49-0.52	210-230	906
3-3	100-500	12.4-12.9	5.0-6.0	0.43-0.47	210-220	661

Run: 12 Date: 3/6/86 Time: 15:10

Coal: Minto Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	65.5	SCFM
Tertiary Air:	105.5	SCFM
Purge:	10.0	SCFM
Coal:	1.56	lbs/min
Limestone:	0.66	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	16.2	1.0-1.5	0.54-0.55	260-280	1316
1-2	10,000+	15.8-16.2	1.0-1.5	0.60	270	1318
1-3	10,000+	15.4-15.8	1.0-1.5	0.52	250	1279
2-1	1,300-2,800	15.2	2.5-3.0	0.30-0.40	270	1194
2-2	3,900-8,100	16.2	2.0-2.5	0.46-0.54	250-300	1190
2-3	3,900-7,300	16.2-17.3	1.5	0.52-0.54	220-230	1112
3-1	1,100-8,100	15.2-16.2	2.5-3.0	0.37-0.42	240-260	1031
3-2	400-2,800	15.2-15.4	3.0-3.5	0.36-0.41	220-230	1026
3-3	400-2,800	14.8	4.0-4.5	0.40-0.45	190-220	987

Run: 13 Date: 3/6/86 Time: 18:00

Coal: Minto Ca/S: 1:1

Feed Rates:

Primary Air:	40	SCFM
Secondary Air:	65.5	SCFM
Tertiary Air:	105.5	SCFM
Purge:	10	SCFM
Coal:	1.52	lbs/min
Limestone:	0.25	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	15.4-15.8	1.5-2.0	0.56-0.57	280-300	1353
1-2	5,300-10,000+	15.2-15.8	2.0	0.55-0.56	290-300	1353
1-3	10,000+	15.4-15.8	1.0-2.0	0.46-0.48	315	1293
2-1	3,000-8,300	13.4-14.8	3.5-4.0	0.50-0.52	290-310	1263
2-2	6,400-10,000+	14.5-14.8	2.5-3.0	0.52-0.54	290	1269
2-3	10,000+	13.8-14.8	3.0	0.48	260	1189
3-1	2,900-10,000+	14.8-15.2	2.5-3.0	0.45-0.46	240-265	1088
3-2	500-4,700	14.8-15.2	2.5-3.0	0.48-0.49	210-220	1038
3-3	200-2,400	13.8-14.8	4.0-4.5	0.45-0.49	200-215	1012

Run: 14 Date: 4/6/86 Time: 10:00

Coal: Minto Ca/S: -

Feed Rates:			% of Total Air	%Excess Air
Primary Air:	40.0	SCFM	18.1	22.7
Secondary Air:	118.5	SCFM	53.5	
Tertiary Air:	53.0	SCFM	23.9	
Purge:	10.0	SCFM	4.5	
Coal:	1.55	lbs/min		
Limestone:	0	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	14.8-15.2	1.5-2.5	0.55-0.61	370-430	1224
1-2	1,200-4,600+	14.8-15.2	2.5-3.0	0.56-0.60	450-460	1242
1-3	800-3,700	14.1-14.8	2.5-3.5	0.51-0.52	390-400	1101
2-1	10,000+	15.2	1.0-2.5	0.60	430-500	1105
2-2	2,800-4,500	14.1	2.5-3.5	0.57-0.58	400-510	1129
2-3	800-3,800	14.5-15.4	3.0-3.5	0.52-0.55	370-410	1044
3-1	3,200-4,800	15.8-16.2	1.5-2.0	0.61-0.62	320-430	929
3-2	3,700-6,400	15.4-15.8	1.0-2.5	0.61-0.62	340-410	937
3-3	1,600-5,500	14.8-15.2	2.5-4.0	0.55	310-360	868

Run: 15 Date: 4/6/86 Time: 13:00

Coal: Minto Ca/S: 1:1

Feed Rates:			% of Total Air	%Excess Air
Primary Air:	40.0	SCFM	18.1	25.1
Secondary Air:	118.5	SCFM	53.5	
Tertiary Air:	53.0	SCFM	23.9	
Purge:	10.0	SCFM	4.5	
Coal:	1.52	lbs/min		
Limestone:	0.31	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	14.8-15.2	2.0-2.5	0.60-0.62	490-500	1367
1-2	10,000+	14.5-15.4	3.0-3.5	0.62-0.65	450-490	1350
1-3	10,000+	15.8-16.6	1.0-2.0	0.58-0.61	400-450	1248
2-1	7,300	14.1-14.5	3.0-3.5	0.58	530-560	1274
2-2	10,000+	14.5-14.8	3.5	0.54-0.56	460-480	1271
2-3	6,800	14.5-14.8	3.5	0.57	520	1223
3-1	2,800-3,100	15.8	1.5	0.56-0.57	370-430	1031
3-2	5,600-6,800	15.8-16.2	1.5-2.0	0.57-0.58	360-450	1037
3-3	2,800-10,000+	14.8-15.8	2.5-4.0	0.52-0.62	260-370	968

Run: 16 Date: 4/6/86 Time: 15:00

Coal: Minto Ca/S: 2:1

Feed Rates:			% of Total Air	%Excess Air
Primary Air:	40.0	SCFM	18.1	23.5
Secondary Air:	118.5	SCFM	53.5	
Tertiary Air:	53.0	SCFM	23.9	
Purge:	10.0	SCFM	4.5	
Coal:	1.54	lbs/min		
Limestone:	0.64	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	14.8-15.2	3.0	0.55-0.57	430	1365
1-2	1,200-4,600+	14.8-15.2	2.0-2.5	0.46-0.49	320-400	1365
1-3	10,000+	17.3	1.0-2.5	0.51-0.52	440-490	1308
2-1	10,000+	15.4	1.5-2.0	0.55-0.57	440-480	1272
2-2	4,200-7,200	14.5-15.2	3.5-4.0	0.51-0.54	370-480	1268
2-3	10,000+	14.8	1.0-2.0	0.49-0.51	410-450	1201
3-1	10,000+	16.2-16.6	2.0-2.5	0.52	290-330	1099
3-2	10,000+	15.4-15.8	2.5-3.0	0.54-0.55	230-260	1101
3-3	2,800-4,900	15.8-16.2	2.5	0.46-0.51	320-330	1062

Run: 17 Date: 5/6/86 Time: 10:15

Coal: Minto Ca/S: -

Feed Rates:			% of Total Air	%Excess Air
Primary Air:	40.0	SCFM	26.5	27.0
Secondary Air:	30.4	SCFM	20.2	
Tertiary Air:	70.4	SCFM	46.7	
Purge:	10.0	SCFM	6.6	
Coal:	1.02	lbs/min		
Limestone:	-	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	5,500-6,400	15.8-16.2	1.5-2.5	0.58-0.64	400-410	1184
1-2	4,700	14.8-15.2	2.5-3.0	0.58	410-450	1164
1-3	800-2,300	14.1-15.8	2.5-4.0	0.50-0.55	390-460	1074
2-1	2,000-7,300	15.2-16.2	1.5-2.0	0.61-0.65	310-430	1045
2-2	300-4,500	13.8-16.2	1.5-2.5	0.57-0.61	320-440	1032
2-3	800-2,300	14.8-16.2	1.5-3.0	0.55-0.68	310-420	984
3-1	400-1,300	14.8	3.0-5.0	0.48-0.50	320-400	737
3-2	200-500	13.4-14.5	2.5-4.0	0.43-0.49	280-330	727
3-3	400-1,000	13.8-14.8	4.0-4.5	0.41-0.48	310-400	679

Run: 18 Date: 5/6/86 Time: 13:15

Coal: Minto Ca/S: 1:1

Feed Rates:			% of Total Air	%Excess Air
Primary Air:	40.0	SCFM	26.5	22.2
Secondary Air:	30.4	SCFM	20.2	
Tertiary Air:	70.4	SCFM	46.7	
Purge:	10.0	SCFM	6.6	
Coal:	1.06	lbs/min		
Limestone:	0.21	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	3,000-10,000+	16.6-17.0	2.0	0.66-0.68	370-430	1262
1-2	2,300-3,000	14.8-15.4	2.0-3.0	0.62-0.65	430	1256
1-3	1,800-10,000+	17.0	1.5-2.0	0.61	330-370	1153
2-1	3,000-4,900	15.8-17.0	1.5	0.61	340	1131
2-2	5,200-6,600	15.8	2.0-3.0	0.61-0.64	320-410	1123
2-3	8,700	16.6	0.5-1.5	0.62	200-250	1050
3-1	1,400-4,700	14.8-16.6	2.0-3.0	0.55-0.60	220-310	878
3-2	600,4,400	14.1-15.2	3.5-4.0	0.49-0.52	210-340	875
3-3	200-1,300	14.8-15.4	2.5-3.0	0.47-0.55	250-370	838

Run: 19 Date: 5/6/86 Time: 15:06

Coal: Minto Ca/S: 2:1

Feed Rates:			% of Total Air	% Excess Air
Primary Air:	40.0	SCFM	26.5	29.5
Secondary Air:	30.4	SCFM	20.2	
Tertiary Air:	70.4	SCFM	46.7	
Purge:	10.0	SCFM	6.6	
Coal:	1.00	lbs/min		
Limestone:	0.43	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	3,700-5,500	15.2-15.8	2.0-	0.66-0.68	370-430	1259
1-2	3,700-4,900	14.8-17.0	2.0-3.0	0.62-0.65	430	1262
1-3	4,900-10,000+	16.6-17.0	1.5-2.0	0.61	330-370	1185
2-1	1,200-9,400	15.8-17.0	1.5	0.61	340	1144
2-2	10,000+	17.3-17.8	2.0-3.0	0.62	320-410	1142
2-3	500-4,300	16.2-16.6	0.5-1.5	0.61-0.64	200-310	1084
3-1	2,600-7,200	16.2-16.6	2.0-3.0	0.55-0.60	220-310	909
3-2	400-2,500	15.8-16.2	3.5-4.0	0.49-0.52	210-340	902
3-3	200-600	14.8-16.6	2.5-3.0	0.47-0.55	250-370	858

Run: 20 Date: 6/6/86 Time: 9:58

Coal: Minto Ca/S: -

Feed Rates:			% of Total Air	% Excess Air
Primary Air:	40.0	SCFM	24.6	21.4
Secondary Air:	65.5	SCFM	40.3	
Tertiary Air:	47.0	SCFM	28.9	
Purge:	10.0	SCFM	6.2	
Coal:	1.15	lbs/min		
Limestone:	-			

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	400-4,800	13.8-15.4	3.0-4.0	0.51-0.58	420-510	1204
1-2	200-4,600+	13.4-14.1	4.6-5.4	0.47-0.52	390-480	1198
1-3	200-400	13.4-14.8	4.0-6.0	0.42-0.47	390-470	1096
2-1	4,900-7,200	15.2-16.2	1.3-2.2	0.66	430-500	1094
2-2	10,000+	15.8-16.2	0.8-2.0	0.62-0.66	350-420	1092
2-3	700-3,800	15.4-16.6	1.8-2.5	0.58-0.68	330-410	1036
3-1	10,000+	16.2-17.0	1.0-1.4	0.66-0.72	450-520	784
3-2	4,300-7,000	15.2-15.8	1.6-2.6	0.62-0.65	430-510	782
3-3	2,100-4,200	15.4-16.2	1.5-2.5	0.56-0.58	420-500	736

Run: 21 Date: 6/6/86 Time: 12:50

Coal: Minto Ca/S: 1:1

Feed Rates:			% of Total Air	% Excess Air
Primary Air:	40.0	SCFM	24.6	38.2
Secondary Air:	65.5	SCFM	40.3	
Tertiary Air:	47.0	SCFM	28.9	
Purge:	10.0	SCFM	6.2	
Coal:	1.01	lbs/min		
Limestone:	0.23	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	2,600-2,900	14.8-15.2	4.0	0.57-0.60	510-520	1251
1-2	3,700	14.5-14.8	3.4-4.4	0.56-0.57	500-560	1248
1-3	1,300-4,200	14.8-15.2	5.0	0.55	500	1177
2-1	2,500-4,600	14.1-15.8	2.3-3.0	0.61	500	1138
2-2	400-4,100	14.5-14.8	3.6-4.0	0.57	480-500	1138
2-3	200-1,100	13.8-15.4	3.6-3.9	0.54-0.56	460-540	1073
3-1	400-1,500	14.1-15.4	2.6-4.2	0.50-0.57	380-470	900
3-2	100-200	12.6-14-1	5.2-5.8	0.47-0.48	390-510	898
3-3	0-1,100	12.6-12.9	5.8-6.4	0.40-0.51	430-460	866

Run: 22 Date: 6/6/86 Time: 15:10

Coal: Minto Ca/S: 2:1

Feed Rates:			% of Total Air	% Excess Air
Primary Air:	40.0	SCFM	24.6	26.9
Secondary Air:	65.5	SCFM	40.3	
Tertiary Air:	47.0	SCFM	28.9	
Purge:	10.0	SCFM	6.2	
Coal:	1.10	lbs/min		
Limestone:	0.42	lbs/min		

Gas Sampling and Temperature Profile

Setting	ppm CO	%O_2	%O_2	%SO_2	ppm NO_x	Temp (^oC)
1-1	100+	15.8-16.2	1.8-2.4	0.62-0.64	470-510	1270
1-2	7,600-8,300+	14.8-15.2	3.6-4.3	0.57-0.58	480-520	1266
1-3	4,000-9,200	14.8-16.6	2.0-2.6	0.57-0.60	410-460	1180
2-1	3,200-8,800	15.4-16.6	1.6-2.2	0.60-0.62	460-540	1174
2-2	5,400-9,900	15.8-16.2	2.2-2.7	0.55-0.62	360-490	1174
2-3	400-1,300	14.5-16.2	2.0	0.474-0.58	390-490	1117
3-1	900-3,100	13.8-14.8	3.2-3.6	0.52-0.56	450-510	929
3-2	300-2,500	12.9-14.8	3.2-4.0	0.52-0.57	360-440	923
3-3	100-300	12.9-14.5	5.1-5.6	0.41-0.46	360-450	887

Run: 23 Date: 10/6/86 Time: 12:45

Coal: Devco Ca/S: -1

Feed Rates:			% of Air	% of Total Air	Excess Air
Primary Air:	40	SCFM	19.0	18.4	20.3
Secondary Air:	65	SCFM	30.8	29.9	
Tertiary Air:	105.9	SCFM	50.2	48.7	
Purge:	6.5	SCFM		3.0	
Coal:	1.65	lbs/min			
Limestone:	-	lbs/min			

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	15.4	1.4-1.7	0.46-0.47	310-330	1281
1-2	9,000-10,000+	15.8-16.6	1.0-1.1	0.46-0.49	350	1291
1-3	10,000+	16.6	0.6-1.1	0.48-0.49	300-330	1231
2-1	4,800-7,600	15.8	1.9-2.1	0.46	315	1145
2-2	9,000-10,000+	16.2	0.7-0.8	0.45-0.47	220-280	1122
2-3	10,000+	16.6	0.5-0.4	0.43-0.48	210	1072
3-1	800-2,600	14.1	4.0-4.4	0.39-0.41	250-270	871
3-2	1,250-1,600	13.2-13.8	5.0-5.2	0.36-0.37	230-260	833
3-3	1,400-2,500	14.5-15.2	3.0-4.0	0.40-0.43	250	774

Run: 24 Date: 10/86 Time: 2:56

Coal: Devco Ca/S:

Feed Rates:		% of Air	% of Total Air	% Excess Air
Primary Air:	40	19.0	18.4	21.0
Secondary Air:	65	30.8	29.9	
Tertiary Air:	105.9	50.2	48.7	
Purge:	6.5		3.0	
Coal:	1.64			
Limestone:	0.16			

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	15.4-15.8	1.0-1.25	0.40-0.42	250-300	1224
1-2	4,700-6,550	15.8	1.5-1.7	0.41	350	1228
1-3	2,200-2,400	16.2	1.2-2.0	0.33-0.37	350	1165
2-1	5,600-10,000+	15.8-16.2	1.0-1.2	0.38-0.40	245	1172
2-2	10,000+	16.2	0.95-1.0	0.40-0.41	230-270	1161
2-3	10,000+	17.0	0.40	0.32-0.40	130-150	1089
3-1	500-2,300	14.8-15.4	3.4-4.0	0.33-0.37	270-300	955
3-2	700-3750	13.8-14.8	4.6-5.0	0.36	220-240	951
3-3	250-800	14.5-14.8	3.6-3.8	0.32-0.35	270	893

Run: 25 Date: 10/86 Time: 16:40

Coal: Devco Ca/S:

Feed Rates:		% of Air (excluding purge)	% of Total Air	% Excess Air
Primary Air:	40	19.0	18.4	21.8
Secondary Air:	65	30.8	29.9	
Tertiary Air:	105.9	50.2	48.7	
Purge:	6.5		3.0	
Coal:	1.63			
Limestone:	0.42			

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	15.4	0.6-0.9	0.36	210-230	1270
1-2	10,000+	15.8-16.6	0.6-0.8	0.41-0.42	300	1285
1-3	7,800-10,000+	17.3-17.8	0.8-1.0	0.40-0.41	360	1238
2-1	10,000+	16.2-16.6	0.9-1.0	0.32-0.34	220-260	1211
2-2	10,000+	16.6-17.0	0.6-1.0	0.34-0.36	240-260	1198
2-3	10,000+	17.0-17.8	0.2-0.3	0.295-0.32	150-170	1133
3-1	900-2,300	14.5-15.2	3.6-4.4	0.22-0.27	270	990
3-2	500-600	13.4-14.1	4.8-5.3	0.24-0.26	230-250	967
3-3	600-1,200	14.5-15.4	3.7-4.6	0.22-0.30	240-260	847

Run: 26 Date: 11/6/86 Time: 15:56

Coal: Devco Ca/S:

Feed Rates:		% of Air (excluding purge)	% of Total Air	% Excess Air
Primary Air:	40	30.2	28.4	5.6
Secondary Air:	92.3	69.8	66.5	
Tertiary Air:	-		4.7	
Purge:	6.5			
Coal:	1.20			
Limestone:	-			

Gas Sampling and Temperature Profile

Setting	ppm CO	%O_2	%O_2	%SO_2	ppm NO_x	Temp (^oC)
1-1	600-1,300	15.4-15.8	2.0-2.5	0.40-0.415	580-630	1162
1-2	1,200-4,600+	14.8-15.2	2.2-2.4	0.39-0.41	580-620	1164
1-3	1,650-5,400	15.8-16.6	1.6-2.0	0.415-0.42	580-610	1111
2-1	250-1,700	15.0-16.6	1.8-3.0	0.33-0.39	510-520	957
2-2	200-1,400	14.5-15.4	3.1-3.4	0.34-0.36	550-570	914
2-3	100-150	14.5-15.4	3.5-3.8	0.33-0.345	560-570	820
3-1	200-800	14.7-15.4	3.3-4.2	0.27-0.29	470-490	624
3-2	400-800	14.5-14.8	4.0-4.2	0.30-0.31	450	618
3-3	400-900	13.2-14.1	4.3-5.0	0.295-0.30	410-430	504

Run: 27

Date: 86-06-12

Coal: Devco

Ca/S:

Feed Rates:

% Excess Air
20.9

Primary Air:	40	SCFM
Secondary Air:	118.8	SCFM
Tertiary Air:	52.9	SCFM
Purge:	6.5	SCFM
Coal:	1.65	lb/min
Limestone:		lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1		15.0-16.0	1.6-3.5	0.43	420-410	1347
1-2		15.4-15.6	1.8-1.9	0.44	550-500	1347
1-3		14.0-15.2	1.35	0.380.46	330-265	1291
2-1		15.0-15.2	2.0-2.8	0.36	520-470	1217
2-2		15.2-13.6	3.3-3.9	0.35-0.38	470-440	1206
2-3		15.2-16.0	3.0-3.4	0.38-0.42	490-560	1149
3-1		16.2-16.8	2.0-2.7	0.31-0.35	520-570	944
3-2		13.6-14.4	4.25-5.0	0.37-0.39	420-405	935
3-3		12.8-13.6	4.8-5.1	0.39	410-350	888

Run: 28 Date: 86-06-12

Coal: Devco Ca/S: 0.9:1

Feed Rates:

% Excess Air
21.5

Primary Air:	40	SCFM
Secondary Air:	118.8	SCFM
Tertiary Air:	52.9	SCFM
Purge:	6.5	SCFM
Coal:	1.56	lb/min
Limestone:	0.19	lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1		14.8-16.0	4.0-3.0	0.43	410-470	1340
1-2		14.8-15.2	2.2-3.9	0.39	440-490	1343
1-3		15.6-16.0	1.6-1.7	0.44	440-280	1279
2-1		15.2	3.0-3.2	0.38	530-620	1259
2-2		14.0-15.6	3.1-4.7	0.37	500-570	1254
2-3		14.8-15.0	3.6-4.0	0.36	520-640	1201
3-1		14.8-15.6	3.25-3.8	0.37	470-550	1054
3-2		12.4-13.6	5.0-5.6	0.33	510-470	1048
3-3		12.8-12.6	5.8-6.1	0.29	500-515	1012

Run: 29

Date: 86-06-12

Coal: Devco

Ca/S: 2:1

Feed Rates:

% Excess Air
20.9

Primary Air:	40	SCFM
Secondary Air:	118.8	SCFM
Tertiary Air:	52.9	SCFM
Purge:	6.5	SCFM
Coal:	1.6	lb/min
Limestone:	0.39	lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1		16.0	3.0-3.55	0.39	530-630	1354
1-2		15.2-15.8	2.0-2.22	0.42	490-570	1361
1-3		16.0	1.95	0.44	430-516	1314
2-1		14.8-15.2	3.5-4.2	0.34	515-550	1261
2-2		13.2-16.0	3.8-4.6	0.33	510-580	1251
2-3		14.4-16.0	3.0-3.2	0.34	530-480	1208
3-1		15.2-16.0	3.3-4.0	0.34	400-610	1060
3-2		13.2-14.0	5.3-5.7	0.29	470-480	1043
3-3		12.8-13.6	5.3-5.8	0.28	400-450	1017

Run: 30 Date: 86-06-12

Coal: Devco Ca/S:

Feed Rates:

% Excess Air
22.1

Primary Air:	40	SCFM
Secondary Air:	26.15	SCFM
Tertiary Air:	66.15	SCFM
Purge:	6.5	SCFM
Coal:	1.01	lb/min
Limestone:	--	lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1		15.8-16.0	2.1-2.7	0.41	400-450	1241
1-2		15.2-16.0	2.6-2.7	0.41	380-430	1241
1-3		14.8-15.6	2.8-3.4	0.39	430-490	1184
2-1		15.6-16.0	1.8-2.0	0.38	350-420	1135
2-2		15.6-16.0	2.5-2.0	0.39	330-430	1127
2-3		16.0	2.2-2.4	0.38	350-450	1075
3-1		13.6-14.8	3.8-4.0	0.37	210-300	914
3-2		14.4-15.2	3.6-3.0	0.42	240-275	917
3-3		15.6-16.0	2.0-2.8	0.42	280-320	844

Run: 31

Date: 86-06-12

Coal: Devco

Ca/S: 2:1

Feed Rates:

% Excess Air
26.0

Primary Air:	40	SCFM
Secondary Air:	26.15	SCFM
Tertiary Air:	66.15	SCFM
Purge:	6.5	SCFM
Coal:	1.0	lb/min
Limestone:	0.24	lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1	100+	15.6-16.4	1.7-2.1	0.41	320-410	1281
1-2	100+	14.8-15.6	2.0-2.4	0.41	410-320	1282
1-3	91-100+	15.4-16.0	2.7-2.45	0.40	310-400	1231
2-1	85-100+	16.0-16.8	1.6-2.0	0.33	360-300	1150
2-2	-100+	15.6-16.0	1.6-2.0	0.35	270-310	1137
2-3	-100+	16.0-16.4	1.6-1.4	0.33	190-310	1092
3-1	15-24	14.0-14.8	3.4-4.4	0.32	280-320	919
3-2	35-43	15.2-16.0	3.2-3.5	0.38	200-250	919
3-3	63-100+	16.4-16.8	2.0-1.8	0.45	200-150	855

Run: 32

Date: 86-06-12

Coal: Devco

Ca/S: 0.7:1

Feed Rates:

% Excess Air
24.7

Primary Air:	40	SCFM
Secondary Air:	25.15	SCFM
Tertiary Air:	66.15	SCFM
Purge:	6.5	SCFM
Coal:	1.01	lb/min
Limestone:	0.12	lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1	100+	15.2-16.0	1.8-2.0	0.44	360-420	1286
1-2	80-100+	15.0-15.6	2.0-2.2	0.44	440-360	1290
1-3	100+	15.0-15.6	2.0-1.8	0.42	380-360	1223
2-1	82-100+	15.6-16.4	1.5-1.4	0.41	370-280	1166
2-2	100+	15.6-16.0	1.4-1.6	0.36	280-200	1170
2-3	100+	15.6-16.6	1.5-1.8	0.38	250-280	1101
3-1	36-46	15.2	3.0-3.4	0.40	170-220	938
3-2	25-87	14.4-15.6	3.1-3.4	0.39	220-320	936
3-3	55-100	16.4-16.8	1.6-1.8	0.41	150-230	902

Run: 33 Date: 86-06-13

Coal: Devco Ca/S:

Feed Rates:

			% Excess Air
			35.9
Primary Air:	40	SCFM	
Secondary Air:	59.2	SCFM	
Tertiary Air:	44.1	SCFM	
Purge:	6.5	SCFM	
Coal:	1.0	lb/min	
Limestone:	--	lb/min	

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1		15.2-16.0	2.2-2.8	0.41	600-670	1227
1-2		15.2-16.2	1.8-2.4	0.44	600-630	1220
1-3		15.6-16.8	0.8-2.0	0.44	530-420	1168
2-1		15.6-16.8	1.8-2.4	0.41	550-620	1087
2-2		16.0-16.4	1.5-2.0	0.41	590-610	1080
2-3		16.4-16.8	1.4-1.4	0.44	480-520	1018
3-1		12.8-14.4	4.5-5.2	0.33	490-530	839
3-2		12.8-14.0	4.4-5.3	0.36	485-530	830
3-3		15.2-16.0	2.2-3.0	0.42	440-520	792

Run: 34 Date: 86-06-13

Coal: Devco Ca/S: 1.3:1

Feed Rates:

% Excess Air
33.3

Primary Air:	40	SCFM
Secondary Air:	59.2	SCFM
Tertiary Air:	44.1	SCFM
Purge:	6.5	SCFM
Coal:	1.02	lb/min
Limestone:	0.12	lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1		15.6-16.0	1.6-2.2	0.42	610-630	1241
1-2		14.8-16.0	1.8-2.2	0.44	600-530	1242
1-3		15.6-16.4	1.2-1.4	0.42	490-560	1185
2-1		15.6-16.8	1.8-2.4	0.41	600-500	1122
2-2		16.4-16.8	1.3-1.8	0.42	420-530	1155
2-3		16.4-17.6	1.2-0.9	0.42	460-520	1054
3-1		12.4-14.8	5.0-4.4	0.34	430-540	878
3-2		13.6-14.0	4.0-5.2	0.35	520-440	879
3-3		14.8-16.4	2.8-3.5	0.35	540-480	847

Run: 35 Date: 86-06-13

Coal: Devco Ca/S: 2.3:1

Feed Rates:

% Excess Air
35.9

Primary Air:	40	SCFM
Secondary Air:	59.2	SCFM
Tertiary Air:	44.1	SCFM
Purge:	6.5	SCFM
Coal:	1.00	lb/min
Limestone:	0.24	lb/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%CO_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (°C)
1-1		16.8-16	2.5-3.0	0.31	620-640	1237
1-2		14.4-16	3.6-2.6	0.38	660-580	1232
1-3		15.2-16.8	1.0-2.0	0.40	560-600	1150
2-1		15.6-16.4	2.6-3.3	0.29	660-570	1091
2-2		16.4-15.6	2.3-3.0	0.34	570-630	1089
2-3		16.0-14.4	2.8-4.0	0.25	510-570	1024
3-1		14.8	3.6-4.0	0.34	370-430	898
3-2		14.4-15.0	4.15-4.6	0.31	400-460	882
3-3		14.8-16.0	2.5-3.0	0.33	370-470	895

Run: 36 Date: 23/6/86 Time: 15:15 - 17:20

Coal: Devco Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	65.8	SCFM
Tertiary Air:	105.9	SCFM
Purge:	4.5	SCFM
Coal/Limestone	2.00	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	16.6-17.0	0.5-1.0	0.37-0.39	420-470	1307
1-2	10,000+	14.8-16.2	1.5-2.0	0.37	410	1293
1-3	10,000+	16.2-17.0	1.5-2.0	0.35-0.36	460	1211
2-1	8,700	15.2-16.6	1.5-2.5	0.36-0.37	430-480	1208
2-2	5,500-6,700	15.4-15.8	3.0-3.5	0.36-0.38	420-460	1207
2-3	2,600-10,000+	16.2-16.6	1.5-2.0	0.36-0.37	390-450	1141
3-1	4,100-10,000+	16.2	1.5	0.29-0.33	420-440	991
3-2	2,600-4,500	16.2-17.0	2.0-2.5	0.31-0.33	370-420	985
3-3	1,500-2,200	16.2-17.0	1.5-2.5	0.25-0.28	320-360	937

Run: 37 Date: 23/6/86 Time: 17:40 - 19:50

Coal: Devco Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	118.8	SCFM
Tertiary Air:	52.9	SCFM
Purge:	4.5	SCFM
Coal/Limestone	2.00	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	14.5-14.8	2.5-3.0	0.33	570-620	1321
1-2	10,000+	14.5-15.8	1.5-2.5	0.25-0.35	570-600	1323
1-3	10,000+	16.2-16.6	1.5	0.35-0.36	590-670	1276
2-1	10,000+	14.1-14.5	3.5-4.0	0.34-0.36	530-680	1225
2-2	10,000+	14.1-14.8	3.0-3.5	0.27-0.32	460-550	1216
2-3	6,800-9,400+	15.8-16.2	3.0-3.5	0.32	460-550	1098
3-1	1,500-3,100	16.6	2.0-3.0	0.29	550-660	986
3-2	400-1,900	15.8-16.2	2.0-3.0	0.24-0.27	580-630	971
3-3	400-2,600	14.8-15.8	2.0-3.0	0.24-0.25	570-620	939

Run: 38 Date: 24/6/86 Time: 13:40 - 15:45

Coal: Devco Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	26.15	SCFM
Tertiary Air:	66.15	SCFM
Purge:	4.5	SCFM
Coal/Limestone	1.24	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	4,500-5,300	16.6-17.3	1.4-2.0	0.25-0.27	520-550	1145
1-2	1,900-3,500	17.8	1.4-2.0	0.33-0.34	490-550	1108
1-3	700-2,400	17.0-17.3	1.5	0.36-0.38	470-520	1054
2-1	2,200-6,800	17.3-17.8	0.5-1.0	0.29-0.32	420-500	1016
2-2	200-1,200	17.0-17.8	0.6-1.0	0.24-0.25	430-500	983
2-3	2,600-10,000+	17.0-17.3	1.3-1.8	0.24-0.30	390-470	881
3-1	1,200-3,500	17.3-17.8	0.4-1.2	0.16-0.17	430-460	761
3-2	500-2,900	17.0-17.3	0.6-1.0	0.21-0.22	390-480	746
3-3	1,000-5,500	17.3-17.8	0.8-1.2	0.08-0.09	400-480	670

Run: 39 Date: 24/6/86 Time: 16:02 - 17:48

Coal: Devco Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	59.2	SCFM
Tertiary Air:	44.1	SCFM
Purge:	4.5	SCFM
Coal/Limestone	1.07	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	1,400-2,000	14.8-15.4	3.6-3.8	0.32	580-590	1104.9
1-2	500-600	14.5-15.8	3.4-4.2	0.29	630-640	1125.2
1-3	100-200	14.5-15.4	3.8-4.2	0.24-0.27	620-640	1035.2
2-1	100-200	14.5-15.8	2.8-3.6	0.27-0.28	640-670	1024.6
2-2	100	14.5-15.8	3.0-3.4	0.24-0.26	630-65	950.8
2-3	100	15.4-16.6	2.5-3.2	0.18-0.22	590-640	865.3
3-1	100-200	14.5-15.8	3.2-4.0	0.22-0.23	630-660	908.3
3-2	100	14.1-14.8	4.6	0.15-0.16	660-700	902.4
3-3	100	14.5-14.8	3.8-4.4	0.16-0.17	660-680	689.4

Run: 40 Date: 25/6/86 Time: 15:15 - 16:35

Coal: Minto Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	65.5	SCFM
Tertiary Air:	105.5	SCFM
Purge:	4.5	SCFM
Coal/Limestone	2.13	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	16.2-16.6	2.0-2.8	0.50-0.51	360-370	1343
1-2	6,600-10,000+	15.4-16.6	3.5-3.7	0.51	350-360	1341
1-3	1,100-2,700	14.1-14.5	5.2-5.5	0.45-0.46	360	1240
2-1	6,200-10,000+	15.4-16.2	3.0-3.3	0.52-0.56	280-360	1255
2-2	1,100-10,000+	16.2-17.0	2.5-3.0	0.47-0.51	360	1248
2-3	4,400-5,500	17.0-17.3	2.4	0.51-0.52	310-330	1139
3-1	3,000-9,200	16.2-17.0	2.6-3.0	0.50-0.52	320-350	1112
3-2	3,100-8,300	15.8-16.2	3.4-3.8	0.43-0.48	360-370	1105
3-3	300-6,300	15.8-16.6	3.0-3.8	0.39-0.40	330	1041

Run: 41 Date: 25/6/86 Time: 13:50 - 15:02

Coal: Minto Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	118.0	SCFM
Tertiary Air:	53.0	SCFM
Purge:	4.5	SCFM
Coal/Limestone	2.13	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	10,000+	17.3-17.8	1.0-1.2	0.60-0.62	470-480	1348
1-2	10,000+	17.0-17.3	1.2-1.4	0.61-0.62	420-490	1349
1-3	6,100-8,100	18.2-18.6	1.0-1.4	0.64-0.65	420-460	1239
2-1	10,000+	16.6-17.3	1.7-2.0	0.56-0.57	460-480	1263
2-2	10,000+	16.6-17.3	1.5-1.8	0.57-0.60	400-470	1257
2-3	10,000+	17.8-18.2	0.8-1.0	0.56-0.58	400-410	1142
3-1	8,800-10,000+	18.2	1.3-1.7	0.51-0.55	410-470	1052
3-2	2,900-10,000+	17.8-18.2	1.5	0.49-0.54	420-510	1037
3-3	1,600-5,400	18.2-18.6	1.2-1.4	0.31-0.32	440-530	990

Run: 42 Date: 26/6/86 Time: 11:35 - 12:50

Coal: Minto Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	30.4	SCFM
Tertiary Air:	70.4	SCFM
Purge:	4.5	SCFM
Coal/Limestone	1.50	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	4,900-10,000+	17.3-18.2	0.8-1.2	0.56-0.58	430-470	1297
1-2	7,300-9,900	17.8-18.2	1.6-2.0	0.57-0.60	370-460	1248
1-3	2,900-6,600	18.2	1.5-2.0	0.56-0.58	370-420	1177
2-1	1,100-10,000+	18.2-19.0	1.0-1.2	0.58-0.60	120-220	1166
2-2	3,300-8,500	18.8	1.0-1.5	0.56	330-420	1160
2-3	1,100-6,300	18.8-19.0	0.6-0.8	0.35-0.36	310-330	1030
3-1	4,900-7,300	18.2-19.0	1.2-1.6	0.40-0.41	340-390	950
3-2	1,300-7,000	18.8	0.8-1.2	0.55-0.57	280-370	962
3-3	1,900-6,600	18.8-19.0	0.8-1.2	0.46-0.55	3430-370	871

Run: 43 Date: 25/6/86 Time: 9:45 - 11:21

Coal: Minto Ca/S: 2:1

Feed Rates:

Primary Air:	40.0	SCFM
Secondary Air:	65.6	SCFM
Tertiary Air:	35.2	SCFM
Purge:	4.5	SCFM
Coal/Limestone	1.50	lbs/min

Gas Sampling and Temperature Profile

Setting	ppm CO	$\%O_2$	$\%O_2$	$\%SO_2$	ppm NO_x	Temp (^oC)
1-1	2,500-4,400	18.2	1.2-1.6	0.54-0.55	380-470	1233
1-2	2,100-10,000+	18.2-18.6	0.2-1.4	0.55-0.56	390-410	1215
1-3	1,600-4,400+	18.2-18.6	1.0-1.4	0.60	490-550	1153
2-1	1,900-2,600	18.6-19.0	1.0-1.4	0.5	530-550	1138
2-2	1,400-4,700	18.6	1.2-1.8	0.57	370-470	1131
2-3	1,300-4,400	17.8-18.0	0.8-1.2	0.47-0.50	470-540	1040
3-1	400-2,700	17.8-18.6	1.0-1.8	0.30-0.33	470-560	919
3-2	100-4,900	18.2-18.6	1.0-1.5	0.35-0.40	470-580	912
3-3	50-2,300	18.6-19.4	0.2-0.8	0.41-0.51	400-510	884

Cooling Panel Temperature RUN: 11

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	18.0	8.5
1B	11.3	
2A	15.5	
2B	22.5	
3A	10.5	
3B	19.0	
4A	22.0	
4B	14.2	
5B	18.2	
6A	30.1	
7B	26.3	
8A	17.3	
9B	16.5	
CONE	13.8	

Cooling Panel Temperature RUN: 12

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	19.4	8.4
1B	11.2	
2A	20.3	
2B	27.8	
3A	10.5	
3B	23.9	
4A	27.0	
4B	18.4	
5B	23.6	
6A	35.7	
7B	32.7	
8A	22.0	
9B	21.1	
CONE	14.5	

Cooling Panel Temperature RUN: 13

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	29.1	8.4
1B	11.4	
2A	22.0	
2B	30.1	
3A	10.7	
3B	25.9	
4A	28.8	
4B	18.1	
5B	25.6	
6A	40.8	
7B	35.5	
8A	24.3	
9B	23.7	
CONE	17.4	

Cooling Panel Temperature RUN: 14

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	20.1	8.4
1B	10.7	
2A	17.8	
2B	24.1	
3A	10.5	
3B	18.1	
4A	23.5	
4B	12.1	
5B	18.7	
6A	29.7	
7B	59.3	
8A	18.9	
9B	18.3	
CONE	12.0	

Cooling Panel Temperature RUN: 15

Panel	Outlet Water Temp. (^{o}C)	Inlet Temp. (^{o}C)
1A	26.6	8.4
1B	11.1	
2A	21.6	
2B	27.4	
3A	10.9	
3B	19.2	
4A	28.9	
4B	11.9	
5B	21.7	
6A	37.2	
7B	11.0	
8A	21.3	
9B	21.6	
CONE	15.7	

Cooling Panel Temperature RUN: 16

Panel	Outlet Water Temp. (^{o}C)	Inlet Temp. (^{o}C)
1A	30.4	8.4
1B	10.6	
2A	23.9	
2B	30.3	
3A	10.9	
3B	19.7	
4A	31.5	
4B	14.0	
5B	23.8	
6A	41.4	
7B	11.2	
8A	25.3	
9B	25.2	
CONE	17.1	

Cooling Panel Temperature RUN: 17

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	25.6	8.4
1B	9.6	
2A	19.6	
2B	24.0	
3A	10.0	
3B	13.0	
4A	26.4	
4B	10.8	
5B	12.8	
6A	26.0	
7B	9.6	
8A	19.0	
9B	18.6	
CONE	11.4	

Cooling Panel Temperature RUN: 18

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	24.6	8.4
1B	10.6	
2A	21.8	
2B	26.6	
3A	10.5	
3B	14.4	
4A	28.0	
4B	12.2	
5B	13.5	
6A	30.8	
7B	9.9	
8A	20.9	
9B	20.8	
CONE	12.5	

Cooling Panel Temperature RUN: 19

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	30.2	8.4
1B	11.3	
2A	22.9	
2B	28.2	
3A	10.5	
3B	14.7	
4A	31.7	
4B	12.0	
5B	14.1	
6A	32.7	
7B	10.1	
8A	22.4	
9B	21.9	
CONE	13.2	

Cooling Panel Temperature RUN: 20

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	24.0	8.6
1B	11.8	
2A	18.7	
2B	21.7	
3A	10.1	
3B	12.8	
4A	25.8	
4B	10.2	
5B	11.7	
6A	26.8	
7B	9.7	
8A	15.2	
9B	15.7	
CONE	11.6	

Cooling Panel Temperature

RUN: 21

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	28.0	8.5
1B	12.5	
2A	21.0	
2B	25.0	
3A	10.5	
3B	14.2	
4A	29.2	
4B	11.3	
5B	12.7	
6A	31.3	
7B	10.0	
8A	18.0	
9B	17.6	
CONE	13.0	

Cooling Panel Temperature

RUN: 23

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	16.9	8.8
1B	15.2	
2A	11.5	
2B	14.1	
3A	10.4	
3B	14.9	
4A	17.3	
4B	24.1	
5B	13.8	
6A	31.9	
7B	10.3	
8A	19.8	
9B	15.2	
CONE	11.7	

Cooling Panel Temperature

RUN: 24

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	17.1	8.8
1B	15.8	
2A	12.3	
2B	17.4	
3A	10.5	
3B	16.5	
4A	19.6	
4B	28.5	
5B	16.1	
6A	33.9	
7B	10.7	
8A	24.7	
9B	20.1	
CONE	13.8	

Cooling Panel Temperature

RUN: 25

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	18.6	8.8
1B	17.5	
2A	12.7	
2B	16.4	
3A	10.6	
3B	17.2	
4A	21.2	
4B	30.8	
5B	16.9	
6A	38.6	
7B	11.0	
8A	26.8	
9B	23.0	
CONE	15.2	

Cooling Panel Temperature RUN: 26

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	15.5	8.8
1B	14.4	
2A	11.6	
2B	13.5	
3A	10.2	
3B	13.2	
4A	16.2	
4B	20.1	
5B	11.7	
6A	23.1	
7B	10.1	
8A	17.4	
9B	14.1	
CONE	10.5	

Cooling Panel Temperature RUN: 27

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	17.0	8.9
1B	15.0	
2A	12.8	
2B	14.0	
3A	11.2	
3B	16.2	
4A	20.1	
4B	23.3	
5B	12.7	
6A	30.1	
7B	35.5	
8A	10.9	
9B	16.7	
CONE	14.9	

Cooling Panel Temperature RUN: 28

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	19.7	8.8
1B	16.1	
2A	13.2	
2B	14.9	
3A	11.3	
3B	16.9	
4A	21.1	
4B	24.7	
5B	13.4	
6A	38.8	
7B	11.3	
8A	20.9	
9B	18.6	
CONE	17.3	

Cooling Panel Temperature RUN: 29

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	21.2	8.8
1B	16.3	
2A	13.7	
2B	15.2	
3A	11.1	
3B	17.8	
4A	21.8	
4B	25.9	
5B	13.9	
6A	40.8	
7B	11.7	
8A	21.6	
9B	19.8	
CONE	18.2	

Cooling Panel Temperature RUN: 30

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	24.3	8.8
1B	16.0	
2A	14.2	
2B	18.6	
3A	10.8	
3B	21.2	
4A	21.5	
4B	23.3	
5B	15.9	
6A	35.0	
7B	13.6	
8A	25.4	
9B	21.2	
CONE	15.4	

Cooling Panel Temperature RUN: 31

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	30.3	8.8
1B	18.2	
2A	14.6	
2B	20.3	
3A	13.1	
3B	28.9	
4A	22.4	
4B	26.1	
5B	16.3	
6A	35.6	
7B	14.7	
8A	25.1	
9B	22.7	
CONE	15.3	

Cooling Panel Temperature RUN: 32

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	28.3	8.8
1B	22.0	
2A	14.8	
2B	24.3	
3A	11.1	
3B	28.9	
4A	22.4	
4B	26.2	
5B	16.2	
6A	35.4	
7B	15.0	
8A	23.9	
9B	20.9	
CONE	14.9	

Cooling Panel Temperature RUN: 33

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	17.7	9.1
1B	13.6	
2A	11.6	
2B	24.4	
3A	10.6	
3B	14.7	
4A	25.9	
4B	22.1	
5B	12.9	
6A	28.9	
7B	10.8	
8A	18.1	
9B	14.8	
CONE	13.2	

Cooling Panel Temperature

RUN: 34

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	17.6	9.0
1B	13.8	
2A	11.8	
2B	25.4	
3A	10.6	
3B	14.8	
4A	27.2	
4B	24.7	
5B	13.2	
6A	30.8	
7B	11.1	
8A	19.4	
9B	15.3	
CONE	13.3	

Cooling Panel Temperature

Panel	Outlet Water Temp. (°C)
1A	17.1
1B	13.8
2A	11.5
2B	16.5
3A	10.3
3B	14.0
4A	27.7
4B	27.6
5B	12.9
6A	30.9
7B	10.7
8A	20.0
9B	15.6
CONE	13.1

Cooling Panel Temperature

RUN: 36

Panel	Outlet Water Temp. (^{o}C)	Inlet Temp. (^{o}C)
1A	18.8	9.6
1B	13.6	
2A	12.5	
2B	13.9	
3A	10.8	
3B	14.7	
4A	32.5	
4B	25.3	
5B	16.6	
6A	48.7	
7B	16.4	
8A	37.5	
9B	22.3	
CONE	15.5	

Cooling Panel Temperature

RUN: 37

Panel	Outlet Water Temp. (^{o}C)	Inlet Temp. (^{o}C)
1A	18.4	9.6
1B	13.6	
2A	12.8	
2B	14.4	
3A	10.9	
3B	14.7	
4A	33.1	
4B	30.0	
5B	17.8	
6A	47.0	
7B	23.2	
8A	38.2	
9B	22.6	
CONE	16.4	

Cooling Panel Temperature

RUN: 38

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	17.8	9.4
1B	13.3	
2A	13.2	
2B	14.2	
3A	11.0	
3B	14.2	
4A	31.8	
4B	21.1	
5B	14.8	
6A	38.6	
7B	14.1	
8A	34.5	
9B	20.6	
CONE	12.5	

Cooling Panel Temperature

RUN: 39

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	18.4	9.4
1B	13.5	
2A	13.1	
2B	14.9	
3A	10.8	
3B	14.5	
4A	32.1	
4B	27.9	
5B	15.6	
6A	40.6	
7B	22.6	
8A	35.5	
9B	21.1	
CONE	13.5	

Cooling Panel Temperature RUN: 40

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	18.8	9.6
1B	13.8	
2A	13.3	
2B	15.5	
3A	12.2	
3B	15.1	
4A	24.2	
4B	22.4	
5B	14.0	
6A	49.8	
7B	12.1	
8A	41.2	
9B	23.7	
CONE	20.2	

Cooling Panel Temperature RUN: 41

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	19.9	9.6
1B	14.4	
2A	13.4	
2B	15.6	
3A	12.2	
3B	15.0	
4A	25.1	
4B	22.6	
5B	14.1	
6A	51.0	
7B	12.5	
8A	42.1	
9B	23.5	
CONE	18.4	

Cooling Panel Temperature

RUN: 42

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	18.7	9.5
1B	13.8	
2A	13.6	
2B	15.4	
3A	11.0	
3B	14.8	
4A	25.1	
4B	22.0	
5B	14.0	
6A	45.6	
7B	13.1	
8A	37.5	
9B	22.2	
CONE	15.5	

Cooling Panel Temperature

RUN: 43

Panel	Outlet Water Temp. (°C)	Inlet Temp. (°C)
1A	18.3	9.6
1B	13.4	
2A	12.9	
2B	14.9	
3A	11.1	
3B	14.5	
4A	23.5	
4B	20.3	
5B	13.8	
6A	42.8	
7B	12.2	
8A	40.0	
9B	21.6	
CONE	14.7	

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JOB NUMBER: 08190005/0003

FOR: P. Salib, Dept. 5

JOB #05000240

Analysis of Coals and Limestone

ULTIMATE ANALYSIS OF COALS (wt%)

Sample	C	H	N	S	O	Ash	Moisture
Minto Coal	63.62	4.49	0.84	6.40	4.28	19.6	0.78
N. S. Coal	62.15	4.28	1.16	3.74	8.43	18.9	1.34

PROXIMATE ANALYSIS OF COALS (wt%)

Sample	Moisture	Ash	Volatile Matter
Minto Coal	0.78	19.6	30.7
N. S. Coal	1.34	18.9	34.8

ASH ANALYSIS OF COALS (wt%)

	Minto Coal	N. S. Coal
SiO_2	36.7	41.9
Al_2O_3	13.03	22.23
Fe_2O_3	37.8	27.1
CaO	2.82	2.49
MgO	0.70	1.04
Na_2O	0.94	1.25
K_2O	2.86	4.11
L.O.I.	2.52	2.22

CALORIFIC VALUE OF COALS

Sample	BTU/lb
Minto Coal	11494
N. S. Coal	10883

ANALYSIS OF LIMESTONE (wt%)

CaO	53.5
MgO	2.44
Fe_2O_3	0.17
SiO_2	2.68
Ignition Loss	41.58

SIEVE ANALYSIS OF LIMESTONE

Mesh Size	Fraction (%)
+400	5.5
-400+200	9.5
-200+100	5.6
-100	79.4

F. E. Campbell

F. E. Campbell
Laboratory Supervisor

FEC/mb/ICAS2

FEC

APPENDIX II

CONTENTS: - Sample Calculation

EXCESS AIR CALCULATION FOR RUN # 24

From Perry's "Chemical Engineer's Handbook" 5th pp. 9-14,15, the volume of theoretical air is given by:

Equ. (9-13), $1710^{*}\ (C/12) + (H_2/4) - (O_2/32) + (S/32)$

= cu. ft air/lb of fuel

where C, H_2, O_2, S are the decimal weights of these elements in lb. of fuel and 1710 is the conversion factor into volume of air at $32^{o}F$.

Volume of Theoretical air/lb fuel:

$$1710^{*}\left(\frac{460+60}{460+32}\right)\left(\frac{0.6215}{12}+\frac{0.0428}{4}-\frac{0.0843}{32}+\frac{0.0374}{32}\right)$$

= 110.3 ft^3/lb fuel

% Excess Air:

$$\frac{\text{Actual Air - Theoretical Air}}{\text{Theoretical Air}} * 100$$

$$\frac{217.4 - (1.64 * 110.3)}{(1.64 * 110.3)} * 100 = 20.3\ \%$$

COMBUSTION EFFICIENCY CALCULATION FOR RUN # 24

Moles Carbon in Coal:

$$1.64 \frac{\text{lbs}}{\text{min}} * 0.625 \frac{\text{lbsC}}{\text{lbs coal}} * \frac{1}{12} \frac{\text{mole C}}{\text{lbs C}} = 1.53 \times 10^{-3} \text{ moles C}$$

Moles Carbon in Limestone:

Moles C = Moles $CaCO_3$

$$0.\frac{16}{\text{min}} * 0.535 \text{ lbs } \frac{CaO}{\text{lbs}} * \frac{1}{56} \frac{\text{moles}}{\text{1b CaO}} = 1.53 \text{ E-3 moles C}$$

Moles Carbon Fed:

Moles C in coal + moles C in limestone

$84.94 \times 10\text{-}3 + 1.53 \times 10^{-3} = 86.47$ E-3 moles C in

Moles Carbon out:

Using N_2 as a tie substance

$$\frac{14.7 * 217.4 \text{ CFM}}{10.173 * (460+60)} * 0.79 = 452.50 \times 10^{-3} \text{ moles } N_2 \text{ in air}$$

$$1.64 * \frac{0.0116}{28} = 0.68 \times 10^{-3} \text{ moles } N_2 \text{ in coal}$$

% N_2 in Gas Analysis:

$$\%N_2 = 100-\%CO-\%CO_2-\%NO_x-\%O_2-\%SO_2$$

$100-0.1380-14.68-0.026-4.07-0.346 = 80.74$ % N_2 in exit gas

Moles Carbon out:

$$\frac{\text{Moles } N_2 * (\%CO+\%CO_2)}{80.74}$$

$$\frac{(452.50 \times 10^{-3} + 0.68 \times 10^{-3}) * (0.138 + 14.68)}{80.74}$$

$= 83.27 \times 10^{-3}$ moles C out

% Combustion Efficiency:

(moles C out/moles C in) *100

$$\frac{83.27 \times 10^{-3}}{86.47 \times 10^{-3}} * 100 = 96.3\%$$

CORRECTED SULPHUR REDUCTION CALCULATION FOR RUN # 24

From baseline test #23 find possible sulphur composition of coal by assuming 0% sulphur reduction.

For 0% Sulphur reduction (run #23): S in = S out

Sulphur out:

$$(452.5\ E\text{-}3 + 1.65 * \frac{0.0116}{28}) * (\frac{0.393}{80.98}) = 2.199\ E\text{-}3\ \text{moles/min}$$

Composition of sulphur in:

$$2.199\ E\text{-}3\ \frac{\text{moles}}{\text{min}} * 32\frac{\text{lbs S}}{\text{mole}} * \frac{1\ \text{min}}{1.65\ \text{lbs}} = 0.0427$$

Corrected sulphur in for Run # 24:

$$1.64 * \frac{0.0427}{32} = 2.186\ E\text{-}3\ \text{moles/min}$$

% Sulphur reduced:

$$\frac{(2.186\ E\text{-}3 - 1.942\ E\text{-}3)}{2.186\ E\text{-}3} * 100 = 11.1\%$$

SULPHUR REDUCTION CALCULATION FOR RUN # 24

Moles Sulphur in Coal:

$$1.64 \frac{\text{lbs}}{\text{min}} * \frac{0.0374}{32} \frac{\text{moles S}}{\text{lbs}} = 1.913 \text{ E-3 moles S/min}$$

Using N_2 as a tie substance (refer to combustion efficiency calculation)

Moles Sulphur Out:

$$\text{moles } \% N_2 * (\%SO_2)$$

$$(452. \text{ E-3} + 0.68 \text{ E-3}) \times \frac{(0.346)}{80.74} = 1.942 \text{ E-3}$$

% Sulphur Reduced:

$$\frac{(\text{Moles S in} - \text{Moles S out})}{\text{Moles S in}} * 100$$

$$\frac{(1.913 \text{ E-3} - 1.942 \text{ E-3})}{1.913 \text{ E-3}} \times 100 = -1.5\% \text{ Sulphur reduced}$$

Velocity - Residence Time Calculations

Minto Coal Tests # 11, # 12 & # 13
$1*10^6$ Btu/hr
50:50 Air Distribution

A. Sample Port 1 Data:
T= 1307°C = 2845°R
Q= 221 SCFM
X-Area = π ft.^{2}

(i) Velocity at Port 1

$$V_1 = \frac{Q\ ACFS}{A\ ft^2}$$

$$Q_1 = 221\ \frac{ft^3}{min} * \frac{1min}{60s} * \frac{(2845)}{(520)}$$

= 20.15 ACFS

$$V_1 = \frac{20.15 ACFS}{\pi\ ft.^2}$$

= 6.41 ft/s

(ii) Residence Time to Port 1

$$\Delta t_{0,1} = \frac{\Delta h_{0,1}}{v_1} = \frac{4.66ft}{6.41ft/s}$$

= 0.73 s

(iii) Total Residence Time to Port 1

$$t_1 = \Delta t_{0,1}$$

= 0.73 s

B. Sample Port 2 Data:
T= 1201°C = 2654°R
Q= 221 SCFM
X-Area = π ft.^{2}

(ii) Velocity at Port 2

$$V_2 = \frac{Q\ ACFS}{A\ ft^2}$$

$$Q_2 = (221)\ \frac{(1)}{(60)}\ \frac{(2654)}{(520)}$$

= 18.80 ACFS

$$V_2 = \frac{18.80 ACFS}{\pi\ ft^2}$$

= 5.98 ft/s

(ii) Residence Time Port 1 to Port 2

$$\Delta t_{1,2} = \frac{\Delta h_{1,2}}{(v_1+v_2)/2} = \frac{3.00ft}{6.20ft/s}$$

= 0.48 s

(ii) Total Residence Time to Port 2

$$t_2 = \Delta t_{0,1} + \Delta t$$

= 0.73 s to .48 s

= 1.21 s

C. Sample Port 3 Data:
T= 984°C = 2263°R
Q= 221 SCFM
X-Area = π ft.^{2}

(iii) Velocity at Port 3

$$V_3 = \frac{Q\ ACFS}{A\ ft^2}$$

$$Q_3 = (221)\ \frac{(1)}{60}\ \frac{(2263)}{(520)}$$

= 16.03 ACFS

$$V_3 = \frac{16.03 ACFS}{\pi\ ft^2}$$

= 5.10 ft/s

(iii) Residence Time Port 2 to Port 3

$$\Delta t = \frac{\Delta h_{2,3}}{(v_2+v_3)/2} = \frac{6.33ft}{5.54\ ft/s}$$

= 1.14 s

(iii) Total Residence Time to Port 3

$$t_3 = \Delta t_{0,1} + \Delta t_{1,2} + \Delta t_{2,3}$$

= 0.73 s + 0.48 s + 1.14 s

= 2.35